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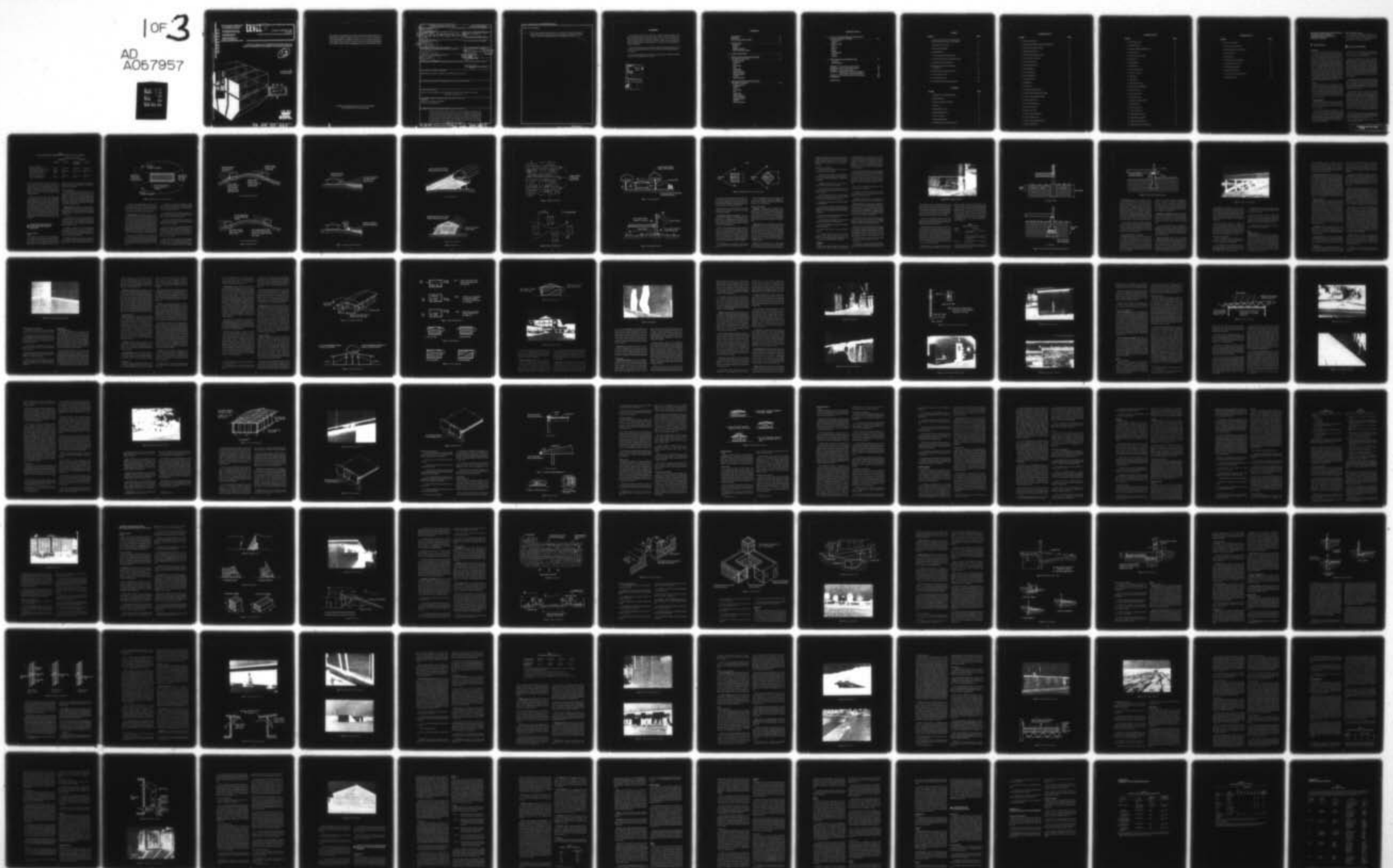

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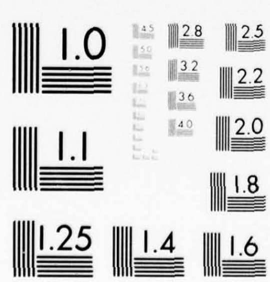

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July 1978
Vertical Construction in Desert and Tropic Regions

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MATERIAL, DESIGN, AND CONSTRUCTION GUIDELINES FOR VERTICAL CONSTRUCTION IN DESERT AND TROPICAL REGIONS

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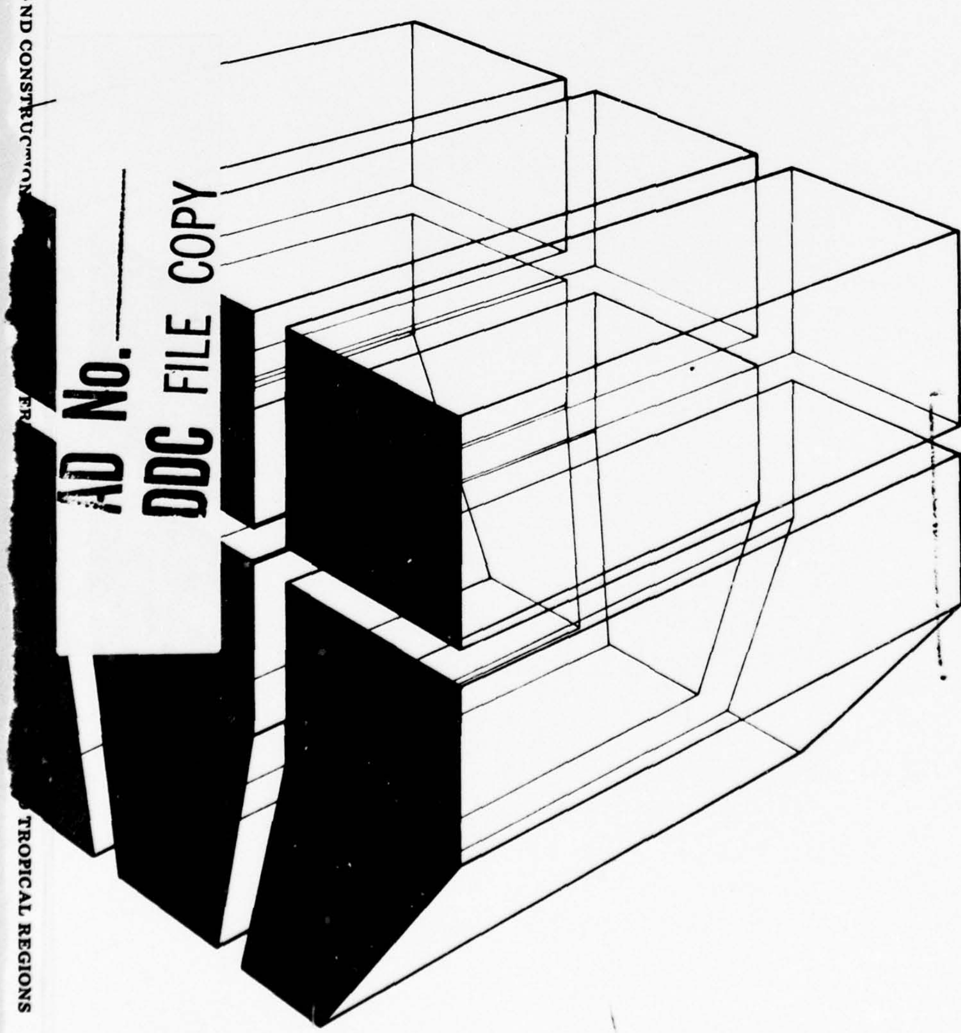

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REPORT DOCUMENTATION PAGE

READ INSTRUCTIONS BEFORE COMPLETING FORM

1. REPORT NUMBER (14) CERL-TR-M-239	2. GOVT ACCESSION NO.	3. RECIPIENT'S CATALOG NUMBER
4. TITLE (and Subtitle) (6) MATERIAL, DESIGN, AND CONSTRUCTION GUIDELINES FOR VERTICAL CONSTRUCTION IN DESERT AND TROPICAL REGIONS.		5. TYPE OF REPORT & PERIOD COVERED (9) FINAL rept.,
		6. PERFORMING ORG. REPORT NUMBER
7. AUTHOR(s) (10) Anthony M. Kao, Kevin Krumdieck		8. CONTRACT OR GRANT NUMBER(s)
9. PERFORMING ORGANIZATION NAME AND ADDRESS CONSTRUCTION ENGINEERING RESEARCH LABORATORY, P.O. Box 4005, Champaign, IL 61820		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS (16) 4A762719AT41-T5-004 (17) T5
11. CONTROLLING OFFICE NAME AND ADDRESS (12) 109 p.		12. REPORT DATE (11) July 1978
		13. NUMBER OF PAGES 106
14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office)		15. SECURITY CLASS. (of this report) Unclassified
		15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

Approved for public release; distribution unlimited.

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

Copies are obtainable from National Technical Information Service
Springfield, VA 22151

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

shelters
tropical and desert regions
vertical construction

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

This report provides a simple description of the basic principles and guidelines that should be observed in selecting materials for shelters, in designing and planning shelters, and in constructing shelters in desert and tropical climates. The report identifies preferred construction materials, design methods, and construction techniques for buildings to be located in these two climatic regions. The guidelines presented in the report are based on actual field experience by the Army, Navy, and Air Force as well as research of existing literature pertinent to construction in desert and tropic regions.

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FOREWORD

This study was performed for the Directorate of Facilities Engineering, Office of the Chief of Engineers (OCE), under Project 4A762719AT41, "Design, Construction, and Operations and Maintenance Technology for Military Facilities"; Task T5, "Research for Base Development in Theater of Operations"; Work Unit 004, "Vertical Construction in Desert and Tropic Regions." The QCR number is 1.07.002. The OCE Technical Monitor is Mr. G. E. McWhite.

The work was conducted by the Engineering and Materials Division (EM), U.S. Army Construction Engineering Research Laboratory (CERL). The Principal Investigator is Dr. A. M. Kao.

COL J. E. Hays is Commander and Director of CERL, and Dr. L. R. Shaffer is Technical Director. Dr. G. R. Williamson is Chief of EM.

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MATERIAL, DESIGN, AND CONSTRUCTION GUIDELINES FOR VERTICAL CONSTRUCTION IN DESERT AND TROPICAL REGIONS

1 INTRODUCTION

Background

In the past, building materials and systems used by the U.S. Army in tropical and desert regions have seldom differed greatly from those used in the temperate zone in the continental United States (CONUS). Although some building materials and systems may be found that could function with equal effectiveness in all climatic zones, such systems would undoubtedly be uneconomical and impractical for military applications. The use of improper building materials, construction details, or building systems which could result would not only adversely affect the working effectiveness or living comfort of the occupants because of inferior or unsatisfactory environments but would also cause unnecessary maintenance problems for facility engineers. Consequently, information on the performance of various building materials, construction details, and building systems in the tropics and desert is needed.

Purpose

The purpose of this report is to provide material, design, and construction criteria or guidelines for use by the Army in theaters of operations (TO) located in desert and tropical regions. The guidance will help the Corps in selecting the materials, construction details, and systems that will result in providing the best human environment in such areas consistent with military objectives and economy.

Approach and Scope

Findings in this report were based on actual field experiences of the Army, Navy, and Air Force, and on a review of literature pertinent to construction in desert and tropical regions.

To broaden the usefulness of this report, all information that relates to vertical construction in desert and tropic regions, whether for permanent or temporary construction, was considered in the development of the guidelines. Whenever possible, however, attempts were made to identify guidelines that apply specifically to a cerrtain type of construction.

Mode of Technology Transfer

It is anticipated that the guidelines developed in this study will impact on the development of future Army Facilities Components System (AFCS) guidelines contained in TM5-301, TM5-302, and TM5-303.[1]

2 CLIMATIC CONDITIONS

The AFCS[2] uses four climatic zones to describe the climates of the world: (1) temperate zone, (2) frigid zone, (3) tropical zone, and (4) desert zone.

Deserts are characterized by a season of very high temperatures (85 to 125°F [29 to 52°C]), with generally moderate night temperatures (60 to 80°F [16 to 27°C]). They have short winters with low rainfall, moderate temperatures during the day, and low temperatures at night (30 to 50°F [−1 to 10°C]). Tropics differ from deserts in having high humidity throughout the year, even in dry seasons, and a small variation between day and night temperatures (75 to 95°F [24 to 35°C] in the hot season, 50 to 70°F [10 to 21°C] in the cold season).

The tropical and desert zones are each further divided into two categories: wet-warm and wet-hot for tropical zones and humid-hot and hot-dry for desert zones. Table 1 summarizes the temperature, relative humidity, and solar radiation values defined by the AFCS for each category in the two zones.

In tropical areas, wet-warm conditions are generally found under the canopy of heavily forested areas, whereas wet-hot conditions are found in the open. Wet-hot regions are characterized by a relatively higher temperature, much higher wind, and more intense solar radiation than is found in wet-warm regions. In wet-hot regions the AFCS design wind speed for facilities with a life expectancy of less than 5 years, such as those located in the TO, is 45 knots for a 5-minute period, with gusts to 65 knots. Designs with a life expectancy of 5 years or more may be subjected to winds of 55

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[1] *Army Facilities Components System—Planning*, TM5-301; *Army Facilities Components System—Designs*, TM5-302; *Army Facilities Components System—Logistic Data and Bills of Materials*, TM5-303 (Department of the Army, 1973.)

[2] *Army Facilities Components System*, TM5-301 Series (Department of the Army, 1970).

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Table 1
Summary of Temperature, Solar Radiation, and Relative Humidity Extremes for Tropic Regions

	Climatic Zones and Categories			
	Tropical Zone		Desert Zone	
	Wet-Warm	Wet-Hot	Humid-Hot (Coastal-Desert)	Hot-Dry
Operational Conditions				
Ambient Air Temperature °F (°C)	75 (24)	78-95 (26-35)	85-100 (29-38)	90-125 (32-52)
Reverse Season Air Temperature °F (°C)	40 (4)	40 (4)	32 (0)	25 (-4)
Solar Radiation Btu/sq ft/hr (W/m^2)	Negligible	0-360 (0-1136)	0-360 (0-1136)	0-360 (0-1136)
Ambient Relative Humidity %	95-100	74-100	63-90	5-20
Storage and Transit Conditions				
Induced Air Temperature °F (°C)	80 (27)	90-160 (32-71)	90-160 (32-71)	90-160 (32-71)
Induced Relative Humidity %	95-100	10-85	10-85	2-50

knots for a 5-minute period, with gusts to 85 knots, except at exposed coastal and mountain locations where stronger winds may be experienced. Wind in wet-warm regions is generally light, seldom exceeding 5 knots. Since most facilities are located in open areas (wet-hot conditions), this report is concerned primarily with wet-hot conditions.

Humid-hot conditions in desert zones are limited to the immediate coasts of bodies of water having high surface temperatures, such as the coasts of the Persian Gulf and the Red Sea, and a small region above the Gulf of California in the southwestern United States. Hot-dry conditions are found in the deserts of northern Africa, the Middle East, west Pakistan and India, the southwestern United States, western Mexico, and central and western Australia. Hot-dry regions are slightly warmer and much less humid than humid-hot areas. Design wind speeds specified by the AFCS for desert zones are the same as those specified for tropical zones (wet-hot).

3 DESIGN AND CONSTRUCTION GUIDELINES FOR TROPICAL FACILITIES

Planning and Siting

General

The location of a facility should be determined by analyzing the constraints and features of the site. These factors include: (1) the climatic constraints of temperature, precipitation, and prevailing winds, and (2) the natural features of the groundplane, such as the topography, ground cover, drainage patterns, and soil types. Another important site consideration is accessibility to existing roads and utilities.

Climatic Constraints

In a tropical region the climatic constraints are quite severe. The small variation between day and night temperatures in this hot climate offers little relief to inhabitants. In addition, the constantly high humidity hinders the human body's transpiration process. The rainfall in these regions also poses problems since storms are intense and prolonged, causing periodically high water tables and flash flooding.

Solar Orientation. To maintain a comfortable internal temperature for buildings in the tropic zone, adequate protection from the sun must be provided. Solar radiation's effect on building surfaces can be controlled in several ways:

1. Building forms should be elongated in plan and their long axis should be sited in an east-west direction as shown in Figure 1. This configuration minimizes the wall areas exposed to the low angles of the early morning and late afternoon sun.

2. Buildings on rolling or hilly sites should be placed on the shaded slope (the north slope in the northern hemisphere, the south in the southern hemisphere, or the east slope in either hemisphere) since these slopes receive less radiation (see Figure 2).

3. Buildings should be located away from reflective surfaces such as large paved areas or water bodies to reduce exposure to reflected radiation, as shown in Figure 3.

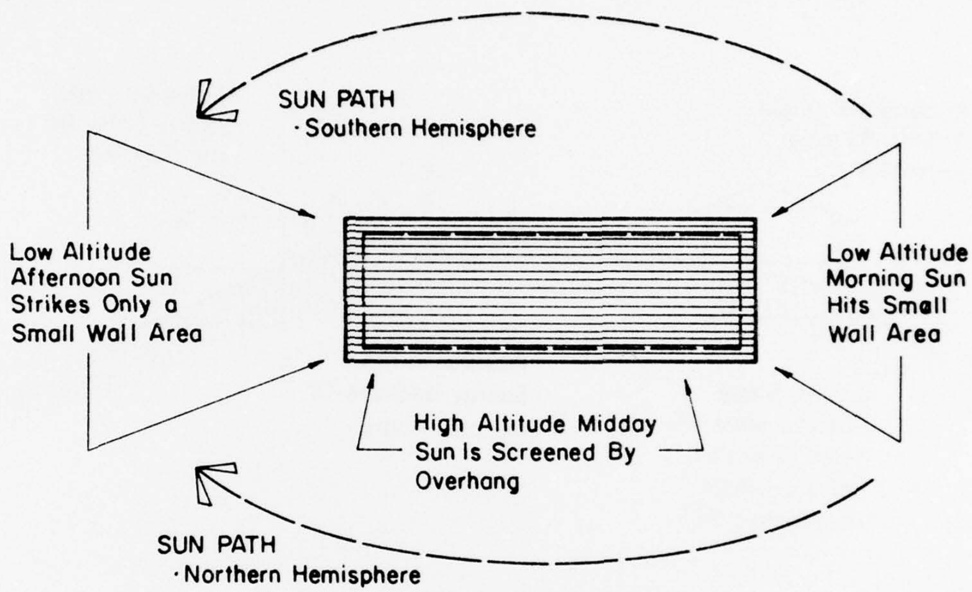


Figure 1. Building layout—east-west orientation.

4. Shading of the entire building unit can also prevent radiation from affecting the interior. Shading can be accomplished by using the natural shading of the site's trees, or, where there are no trees, by creating a man-made screen over the structure (see Figure 4).

Wind Orientation. Wet tropical regions are characterized by mild trade winds which generally blow the same directions for most of the year. During the monsoon season, however, high velocity winds occur from several directions. Because of the infrequency and directional variability of these winds, no simple method of site protection is advised; instead, the individual buildings should be designed for the full brunt of these forces. Designers should follow TM 5-809-11, *Design Criteria for Facilities in Areas Subject to Typhoons and Hurricanes*, for facilities in typhoon and hurricane regions.

Effective use of the trade breezes is a very important site consideration because they provide the only relief to this zone's oppressive heat. By evaporating perspiration from the skin, the winds provide a form of cooling for the inhabitant. Some general guidelines for site layouts are:

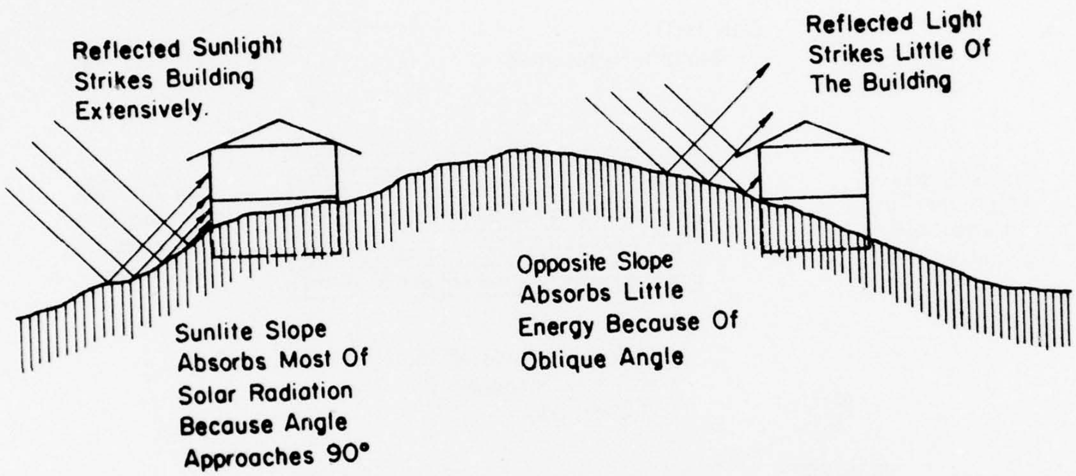
1. Building layouts should be designed to channel the trade winds through the site. If possible open spaces and street patterns should reinforce the prevailing wind direction, as Figure 5 illustrates.

2. A staggered layout of individual buildings will allow better breeze distribution to adjacent structures. Figure 6 shows proper spacing dimensions.

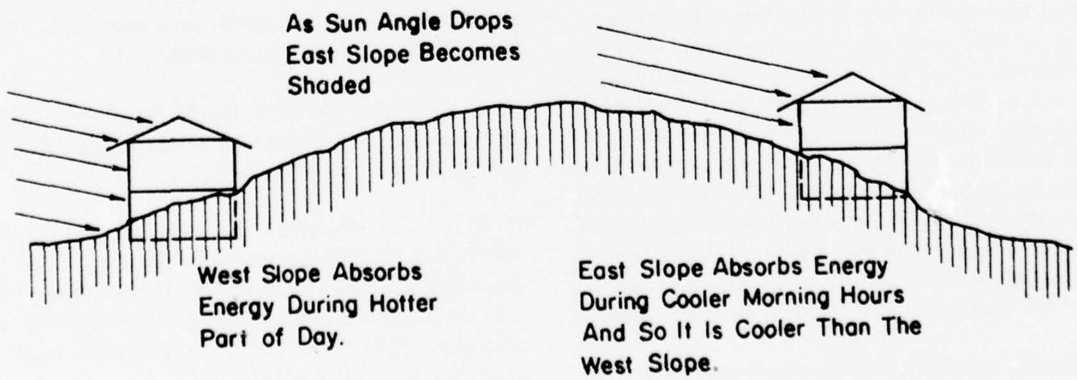
3. Landscape elements should be positioned and maintained to offer minimum resistance to prevailing breezes, as pictured in Figure 7.

4. For both structural and environmental reasons, buildings in this region should be elevated above the groundplane as shown in Figure 8. The resulting air circulation underneath the structure helps to keep the structure cooler. However, the crawl space must be kept open to permit airflow.

5. Since proper solar orientation and prevailing wind orientation often differ, a dilemma arises as to which orientation is most critical. Studies have shown that the airflow through buildings oriented at 45 degrees

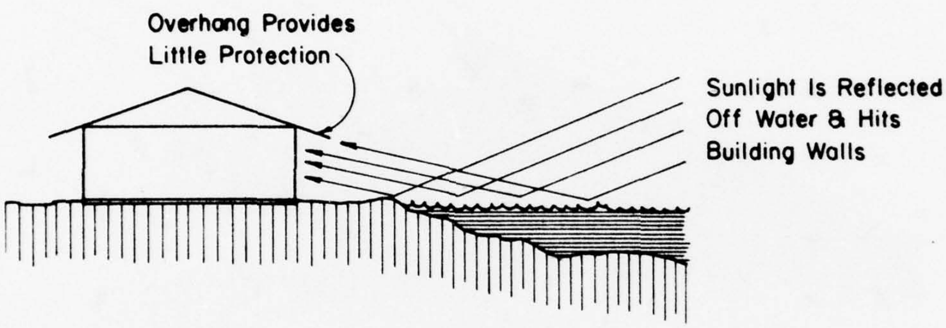


a. North-south slope illustration.



b. East-west slope illustration.

Figure 2. Building placement.



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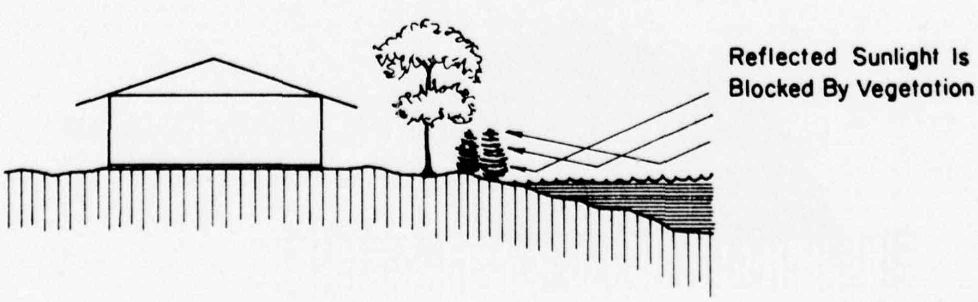
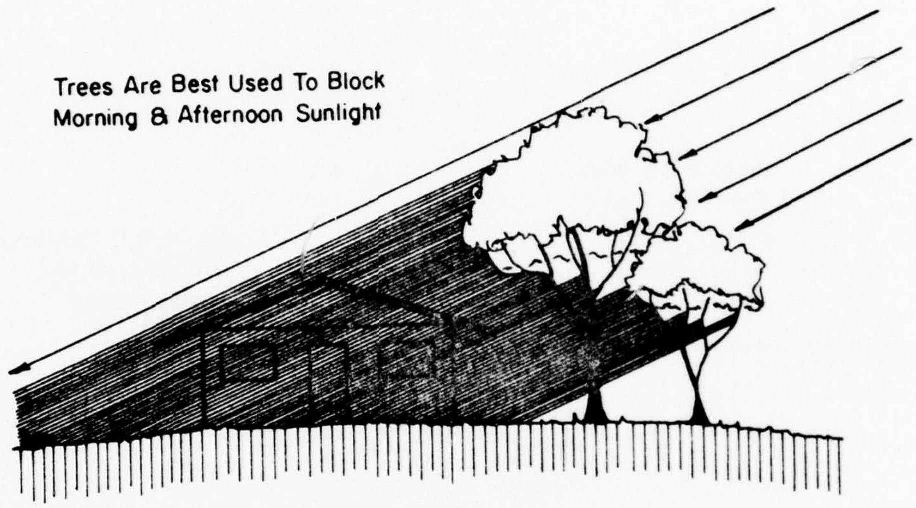
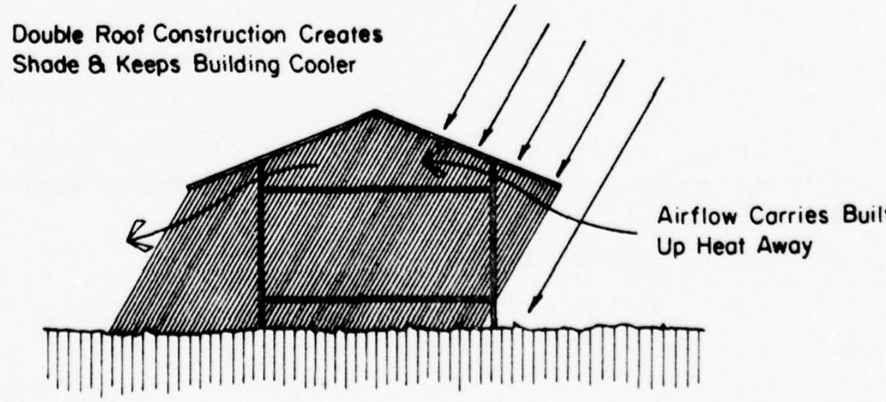


b.

Figure 3. Siting around reflective surfaces.



a. Natural sun screens.



b. Parasol roof construction.

Figure 4. Sunscreens.

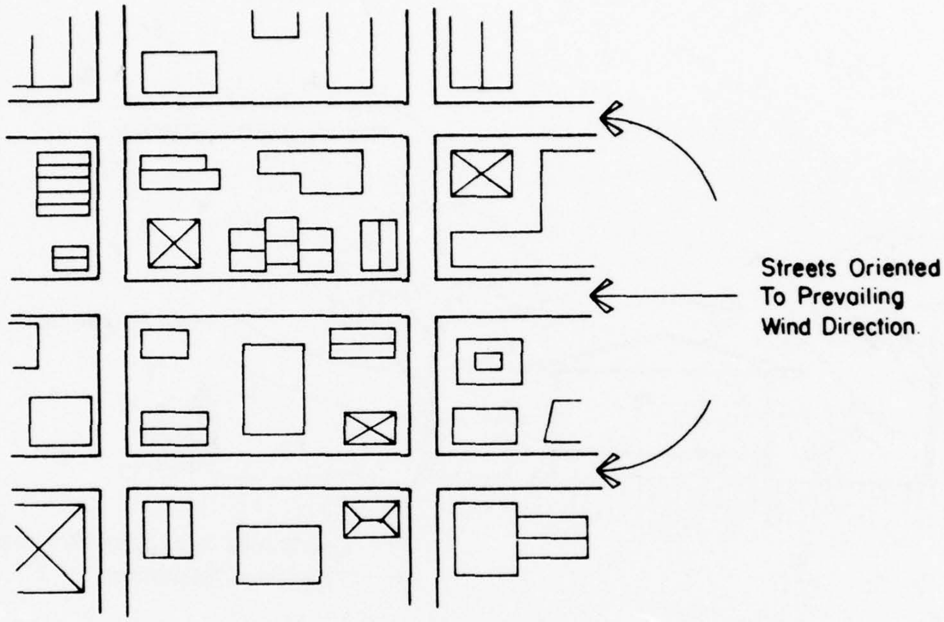


Figure 5. Suggested street layout.

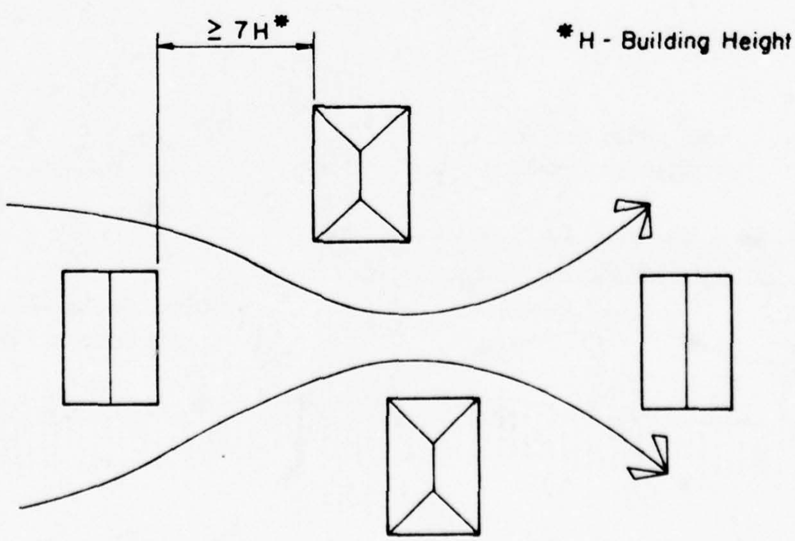


Figure 6. Staggered building layout.

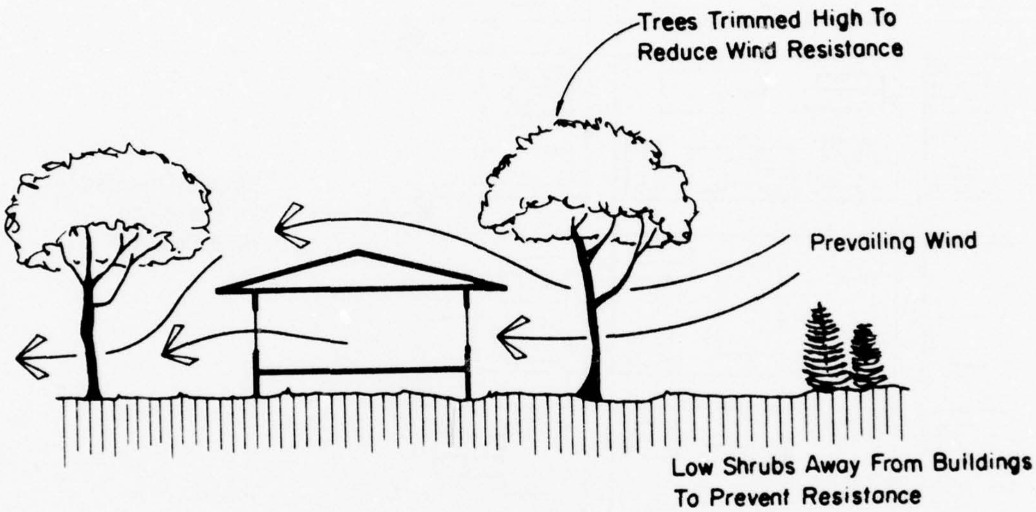


Figure 7. Effects of vegetation.

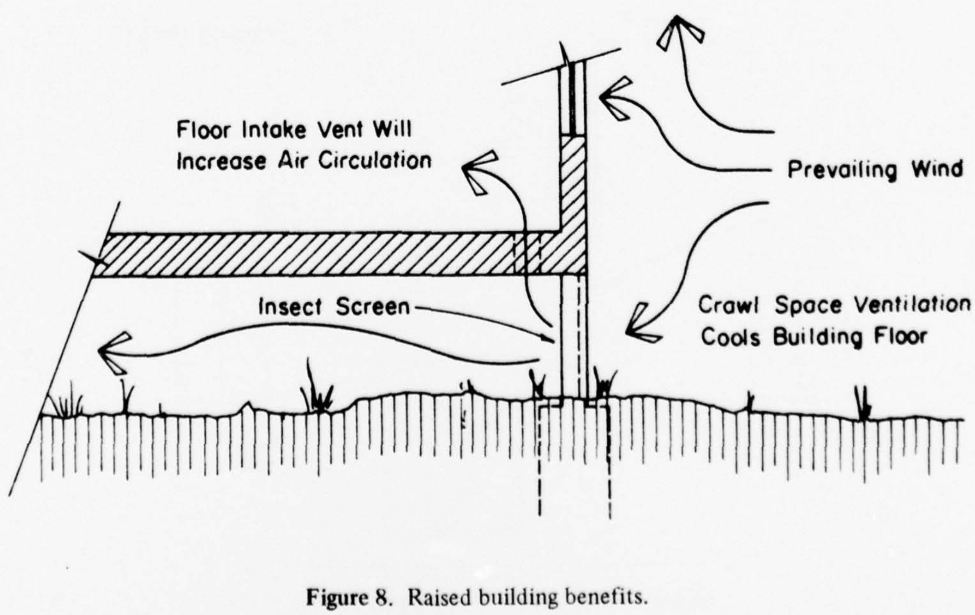


Figure 8. Raised building benefits.

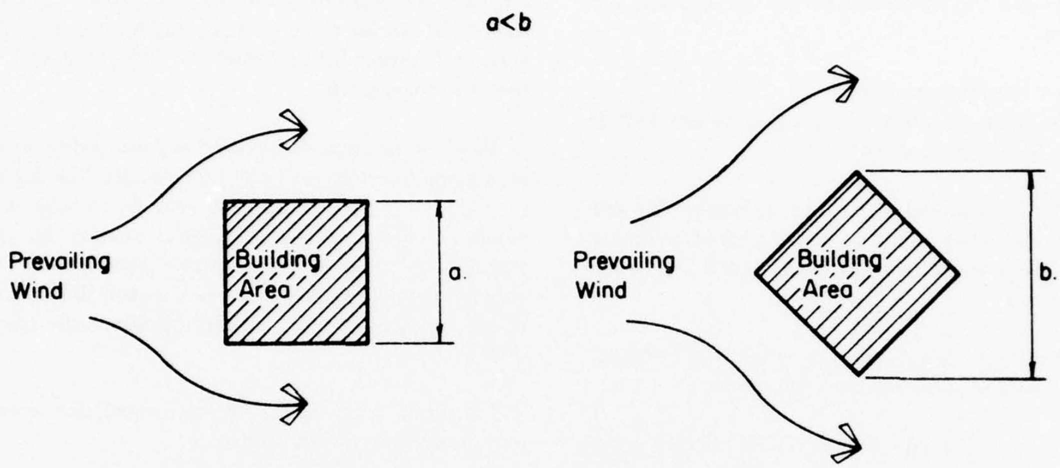


Figure 9. Building orientation for wind penetration.

to the direction of the prevailing wind is greater because of the larger leeward suction forces (see Figure 9).[3] Thus facing a building into the wind does not necessarily increase airflow through it. Consequently, solar orientation should be a more critical consideration.

More specific ways to naturally ventilate individual buildings will be discussed in the section on exterior walls and wall openings.

Rainfall and Humidity Considerations. The heavy annual rainfall in tropical areas profoundly affects the performance of all building types. Precipitation acts directly on the various building materials by weathering them, whereas humidity acts more indirectly by promoting mold and fungus growth.

Because of the typically high winds associated with tropical rain storms, water penetration into the building is a serious problem. Since, as already discussed, trade wind penetration is desirable in terms of cooling, building orientation cannot be altered to provide protection from windblown rain. Instead, this problem must be solved at the scale of individual buildings (see sections Design Considerations and Material Usage).

[3] O. H. Koenigsberger, et al., *Manual of Tropical Housing and Building, Part One: Climatic Design* (Longman, 1973), p 124.

In general, buildings should be sited on high points in the local topography to minimize standing water problems and to maximize the airflow which decreases the effects of heat and humidity.

Natural Site Constraints

Topography. Tropical regions are characterized by periodic heavy rainfalls which rapidly change the water table and result in standing water in low areas. Because of the health hazard created by pools of standing water, the drainage patterns of the site must be considered. Drainage swales should be used to carry away rainfall runoff, and low spots should be filled in or graded to drain.

Vegetation. Plants in tropic regions serve primarily as shading devices. Every effort should be made to retain shade trees on a site and use the shade they provide when determining the location of individual buildings. Generally, the use of local plant types is encouraged for new landscaping since these plants are definitely best suited for the soil and weather conditions. The ficus tree, however, should not be planted adjacent to buildings because its root structure may damage the foundation system.

Soils. The soil conditions of a site in tropical regions will typically limit the placement of major building types. The generally weak, spongy soils and the periodic

swelling and shrinking of soils caused by the heavy rainfall will require special consideration when choosing which foundation systems are best suited for this application. See the foundation section for suggested system types.

Summary Recommendations

1. Buidlings should be elongated in an east-west direction to minimize wall exposure.

2. Buildings should be placed in rolling or hilly sites on the shaded slope (north slope in northern hemisphere, south slope in southern hemisphere) or east slope whenever possible.

3. Buildings should be kept away from reflective surfaces such as paved areas or water bodies.

4. Exposed building surfaces should be made out of reflective materials with low absorption and transmission characteristics.

5. Shade should be provided for the entire building by natural or artificial means (trees or a screen above the roof and one air overhang over the walls).

6. Open spaces and street layouts should be parallel to prevailing winds.

7. The layout of individual buildings should be staggered to provide breeze distribution. For spacing of shelters, the "seven times height" rule can be used as a rough guide.

8. Trees and shrubs should be maintained to offer minimum resistance to prevailing breezes.

9. Buildings should be elevated above the groundplane to provide ventilation underneath them.

10. Protective drainage patterns away from buildings should be maintained.

11. Existing plants should be preserved wherever possible.

12. Local plant types should be used for new landscaping wherever possible. However, the ficus tree should not be planted adjacent to buildings since its root structure may damage building foundations.

Foundations

General

Soils. Tropical regions typically have deep residual soil profiles with medium to high compressibility and low shear strength.[4] However, site analysis of local soils is recommended whenever possible because the depth and quality of residual soils vary significantly. Where a complete soil analysis is not possible, some rough assumptions can be made by analyzing how foundation systems function for comparable existing buildings in the surrounding area.

Residual soils generally expand and shrink depending on seasonal humidity and moisture changes. The degree of volume change in these soils may be as large as 5 percent, which can place excessive stresses on the foundations.[5] Figure 10 illustrates a possible effect of these stresses. The organic layer of topsoil should also be avoided because of its highly unstable nature under load.

Protection from differential settlement due to volume changes can be achieved by:

1. Carrying the foundation system down below the active soil layer where it will not be affected by seasonal changes in moisture (Figure 11a).

2. Removing the active layer of soil under the foundation and replacing it with inert fill (Figure 11b).

Termite Protection. Tropical regions are highly susceptible to termite attack. Both drywood and subterranean species are encountered, depending on the location. Listed below are guidelines for protection from subterranean species. When drywood termites are present in the surrounding area, the only effective method of control is to use pressure-treated lumber.

Subterranean termites are abundant in tropical areas because of warm temperatures, low altitude, and high humidity. Damage from these termites can be minimized by using chemical or mechanical barriers.

Toxic chemicals can be used to poison the soil around the building or to poison the wood itself. Soil treatment is most effective if applied during foundation construction. Properly installed, such a poisonous barrier can last indefinitely (current test plots are over 25 years old and are still effective).[6] Chemical migration in most

[4] L. Zeevaert, *Foundation Engineering for Difficult Subsoil Conditions* (Van Nostrand Reinhold Co., 1972), p 15.

[5] Zeevaert, p 16.

[6] H. R. Johnston, et al., *Subterranean Termites, Their Prevention and Control in Buildings*, Home and Garden Bulletin No. 64 (U.S. Department of Agriculture [USDA], 1972), p. 25.

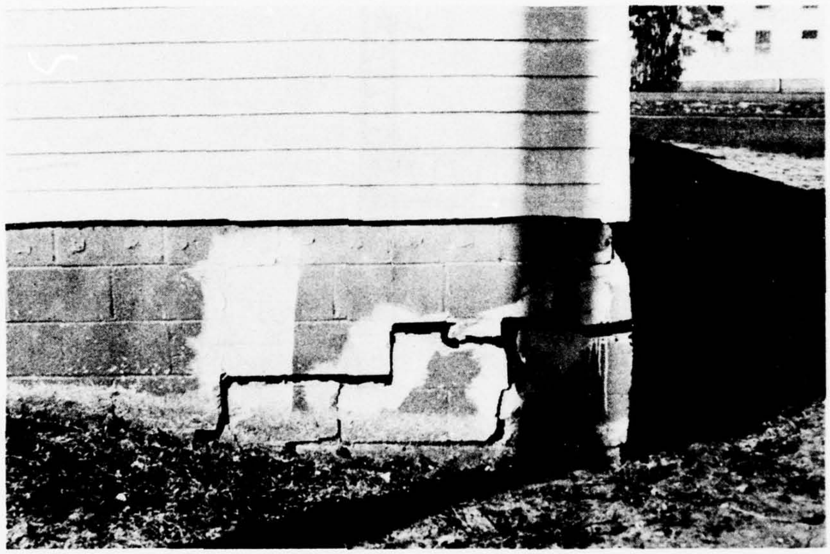


Figure 10. Foundation settlement.

soils is minimal: therefore only physical erosion of the treated soil or the placing of additional untreated soil over the treated areas will render this method ineffective. However, local groundwater could be contaminated if the insecticide is applied to soils containing layers of gravel or soils that crack up in periods of drought. For such locations, soil poisoning is not recommended.

Currently, two chemicals are suitable for soil treatment in the concentrations listed below in Table 2. See Appendix A for specifications on critical locations and rates of application for soil poisoning.

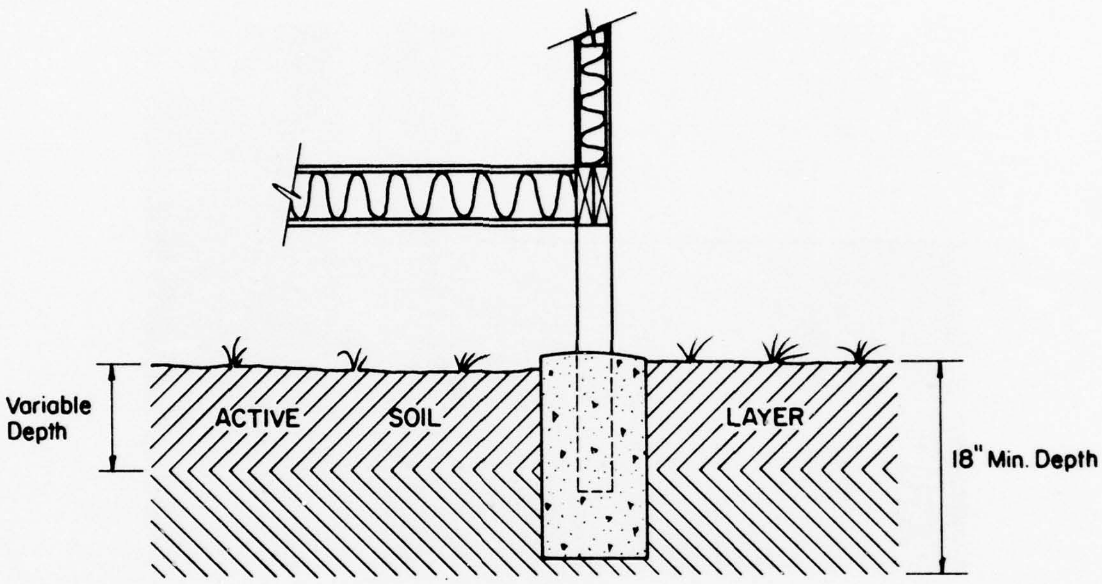
Chemical treatment of the wood itself is also effective in curbing termite damage. This method is recommended when wood is used as a foundation material or where wood comes in contact with the foundation and soil poisoning is not used. Chemicals can be surface applied by brush or spray, allowed to soak in, or pressure treated. Pressure treatment, the most effective method, is widely accepted in the construction industry because of its field performance. Several recommended preservatives are listed in Appendix B.

Mechanical barriers are designed to make the presence of termites known visually. They do not stop termites; they simply make it harder for termites to work undetected. Proper installation and subsequent inspection are required to make the shield effective. Buildings using slab, grade, or shallow perimeter foundation systems do not allow visual inspection of the interior edges of the shield and so other methods of control must be employed. Shields should be made of a durable metal such as aluminum, copper, zinc-copper alloy, terne plate, or galvanized iron or steel. A typical installation is shown in Figure 12.

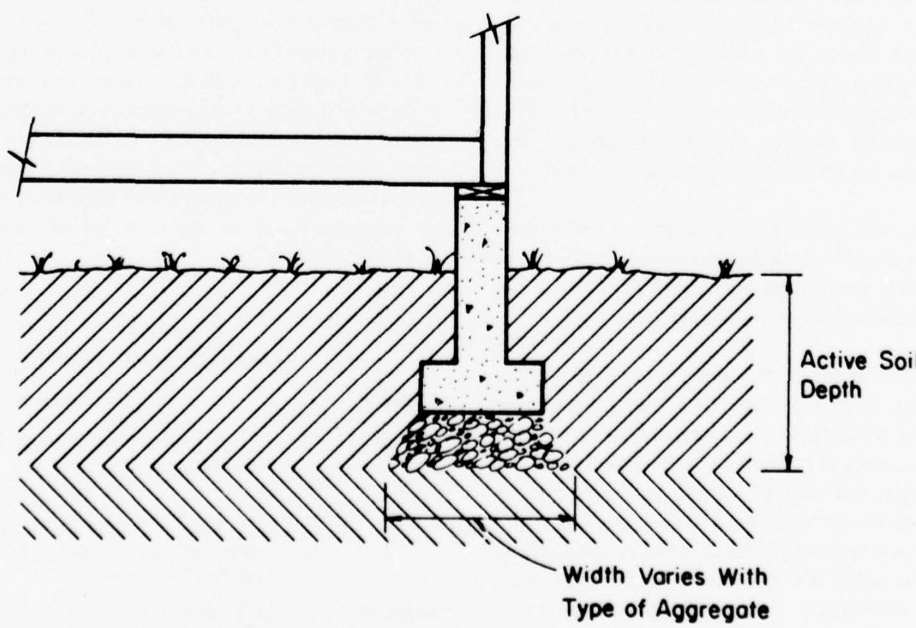
Table 2
Chemicals for Soil Treatment*

Chemical	Concentration
Chlordane	1.0 percent applied in an oil solution or a water emulsion
	or
	2.0 percent applied in an oil solution or water emulsion (used only in severely-infested locations).
Heptachlor	0.5 percent applied in an oil solution or water emulsion.

*(From H. R. Johnston, et al., *Subterranean Termites, Their Prevention and Control in Buildings*, Home and Garden Bulletin No. 64 [USDA, 1972], p 25.)



a. Foundation depth.



b. Infill detail.

Figure 11. Recommended foundation depth and infill detail.

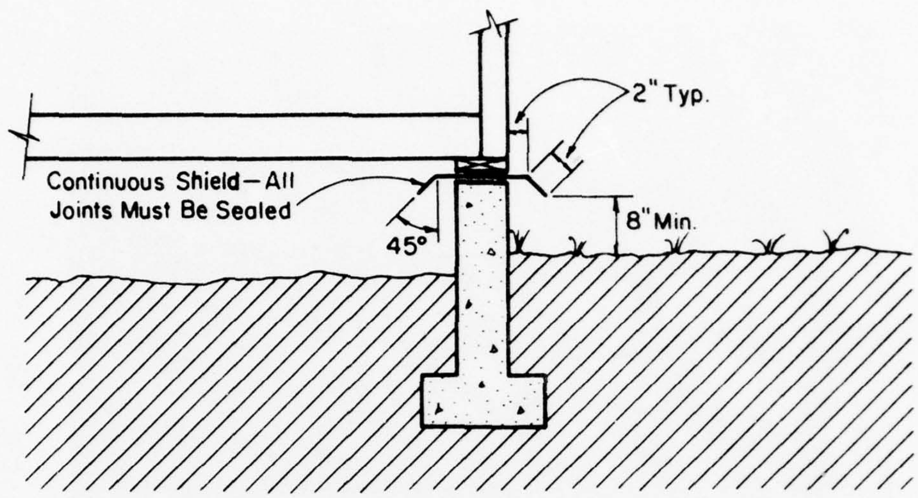


Figure 12. Typical termite shield installation.

Erosion Protection. Once the foundation system is in place it must be protected from wind and water erosion. In tropical areas wind erosion is minimal, but the uplift forces created by wind can be severe in some localities. Uplift of a building using piers or perimeter footings is counteracted by the weight of the structure and the gravity forces of the overlying soil. Since the weight of the overlying soil can be the most significant downward force in lightweight buildings, erosion must be prevented. In addition, when the backfill is treated for termite control, erosion must be prevented so that the termite protection is not washed away with the soil.

Erosion occurs from the heavy rainfall runoff associated with tropical areas. It is prevented around building edges by carrying roof drainage systems out away from the exterior walls, properly grading the soil away from the building walls, and providing larger site drainage patterns to carry the runoff away.

Systems and Materials Recommendations

General. Because of the extreme heat and humidity in tropical areas, buildings should be constructed on stilts whenever possible (Figure 13). The raised-point foundation absorbs much less of the stored heat from the ground, allows the floor system to be cooled by natural ventilation, and separates the building from the high moisture content of the ground. These advantages suggest that raised-point foundations are the best solution for tropical areas.

Reinforced concrete and masonry are suggested materials for foundations in tropical areas. Reinforcing steel used in concrete and masonry members must be adequately protected to prevent corrosion (see Chapter 5). Pressure-treated wood can also be suitable but is not recommended for permanent construction because of its variable life in tropical areas.

Raised-Point Foundations. Raised-point supports may be either bearing piers, which use a bearing pad to distribute the building load, or friction piles, which transfer the building load to the soil by the friction created between the pile surface and the surrounding earth.

A raised-point foundation system is generally the simplest and probably the cheapest foundation for lightweight buildings. Raised-point supports are most efficiently used at locations where ground elevations vary considerably, since they require minimal site preparation and installation.

Perimeter Footings. Concrete slabs on perimeter footings have been used and are performing satisfactorily in the Panama Canal Zone. Although slab-on-grade systems are generally quite economical and do work in tropical areas, they are not recommended because they place the floor system in direct contact with the moist soil. Moisture problems result and the buildings will receive more reflected heat from the ground.

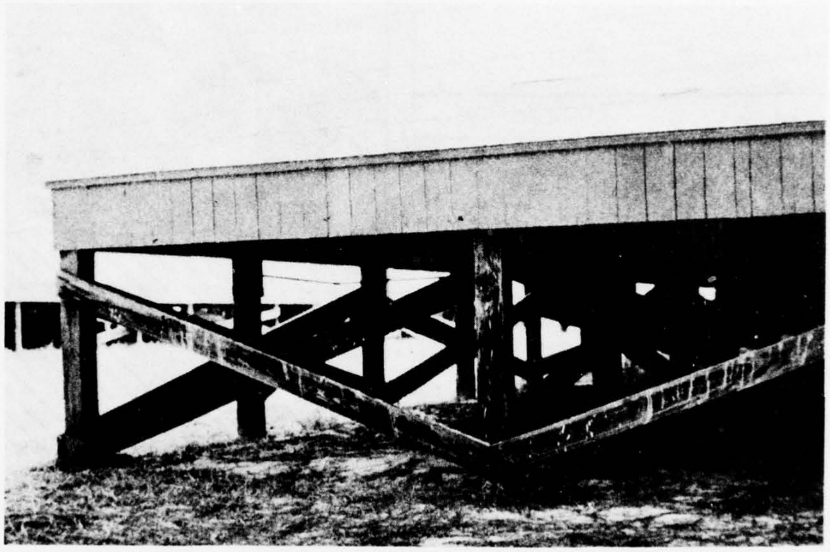


Figure 13. Raised wood foundation.

Raised-perimeter foundations are preferred over slab-on-grade systems becuase the crawl space provided can be ventilated. However, large openings are needed to effectively ventilate the space, suggesting that a raised-point foundation system should be used instead. Nevertheless, for buildings with heavier floor loads, such as storage facilities, a slab-on-grade or raft foundation is still required.

In general, perimeter footings are unsuitable for temporary construction because more extensive site work is required and they are difficult to remove if the building has to be moved. In the tropics this foundation type is further discouraged because its contact with the groundplane restricts ventilation, creates moisture problems, and increases the chances of termite attack.

Summary Recommendations

1. Site soil conditions should be determined by a soil analysis if feasible; if not, assumptions should be based on inspection of local building types.

2. If the building is to be constructed of wood, termite protection will be necessary. Soil under and around the building should be treated with chlordane or heptachlor. Pressure-treated wood should be used.

3. Depending on the severity of local wind and rainfall conditions, the soil around the foundation should be protected from erosion.

4. Once site conditions have been analyzed, the available foundation systems should be reviewed and the best type used in the building design. Raised-point supports (or stilts) are recommended for both permanent and temporary buildings whenever feasible.

5. Concrete, masonry, or treated timber are the recommended materials for foundations.

Floors

Design Considerations

Raised Floors. Raised floors on foundation piers are recommended because this type of construction allows the floor to be cooled by natural ventilation. To insure that the desired airflow occurs, the openings between the floor and ground should be as large as possible. Optimum results can be achieved by constructing the building one full story above the groundplane. Doing so will provide a good airflow, reduce termite and fungus problems, and provide large, shaded, exterior living and storage areas at grade level.

Raised buildings are subject to higher wind loads than conventional buildings at grade level because of the higher exposed building surface. Hence, buildings using raised floors must be designed to insure adequate anchorage to the ground and stability between the individual panels and the foundations.

On-grade Floor Systems. Where raised floors are not feasible, on-grade floor systems are used. Slabs on grade, a floor system commonly used in the semitropical region of the CONUS, cannot be strongly recommended for other tropic regions because they create several problems. Since the floor slab is in direct contact with the wet ground, it will be likely to create moisture problems unless the slab is properly waterproofed and sealed. In addition, because there is no space between the slab and the ground, the building will receive more reflected heat from the ground, natural ventilation cannot be fully utilized to cool the building, and it will be more difficult to control infestation by subterranean termites.

Construction Practices

Moisture Control. Floor systems in tropical regions are exposed fairly often to highly humid air and moist soil conditions. Raised floors should have very few moisture-related problems. To reduce the amount of moisture that may come up from the ground when a slab-on-grade system is used, a 4- to 6-mil polyethylene vapor barrier should be placed over 4 to 6 in. (10 cm to 15 cm) of gravel, which is placed on top of the soil. The gravel serves as a capillary break to stop groundwater flow, and the vapor barrier is used to stop water vapor from rising. Special consideration should be given to insuring that the floor/wall joint detail is watertight, as that area is one in which sealing problems commonly occur.

Insulation. Insulation in the floor system of a naturally ventilated tropical building provides no real benefits. For air-conditioned buildings, insulation is required. The size and type should be determined by the HVAC designer.

Expansion Joints. Interior floors are not subject to the same heat extremes as the roof and the walls; therefore, separation joints are needed between the floor and the wall systems to allow for thermal movement.

Material Usage

General. In fully-air conditioned buildings, any of the common flooring materials may be used. In naturally ventilated buildings fewer choices are available because of the problems of humidity, dirt accumulation, and pests. For reasons of hygiene, only easily cleaned materials as shown in Figure 14 should be used for floor finishes. The following sections list and discuss the best materials for naturally ventilated buildings.

Wood. Hardwood flooring, if protected from moisture extremes and termites, is a suitable flooring material. Oak and maple have performed satisfactorily, but the native species listed in Appendix C can also be used. Pressure-treated plywood (exterior grade) may also be used for flooring if protected from excessive moisture.

Concrete. Concrete floors have proven to be satisfactory for tropical buildings. Additives such as color pigments, hardeners, and nonslip agents are suitable for use provided they contain no ferrous materials. Moisture-curing polyurethane coatings (TT-C-542) are recommended for floors where abrasion resistance and protection from acids, alkalis, and solvents is needed. See sections on "Concrete" and "Reinforcing Steel" for more specific recommendations on the materials to be used and the construction process to be followed.

Tile. Asphalt, vinyl-asbestos, and flexible vinyl tile flooring materials may be used for general-purpose spaces. Vinyl asbestos and similar floor tiles should be warmed to facilitate cutting and bending during installation and to provide good initial contact with the stiff tar-mastic used to glue them in place. Slabs on grade present problems for tiling if they are not adequately waterproofed. Moisture trapped under the tile will cause the tiles to blister. When covering an unprotected slab, only permeable tile should be used. Quarry tile is recommended for kitchen areas and other similar spaces. Ceramic tile is recommended for bathrooms and shower stalls. Based on NAVFAC's experience,[7] cork tile, rubber tile, and linoleum should not be used in naturally ventilated buildings.

Terrazzo. Because it provides a continuous, smooth, and easily cleaned surface, terrazzo is a suitable material for the tropics. Where hygiene is important (as in health-care facilities) terrazzo is an excellent material because the small number of joints reduces bacterial and dirt accumulation.

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[7] *Materials Criteria for Construction in Tropical Environments*, NAVFAC INST 11012.98A (Department of the Navy, 1967), p 22.

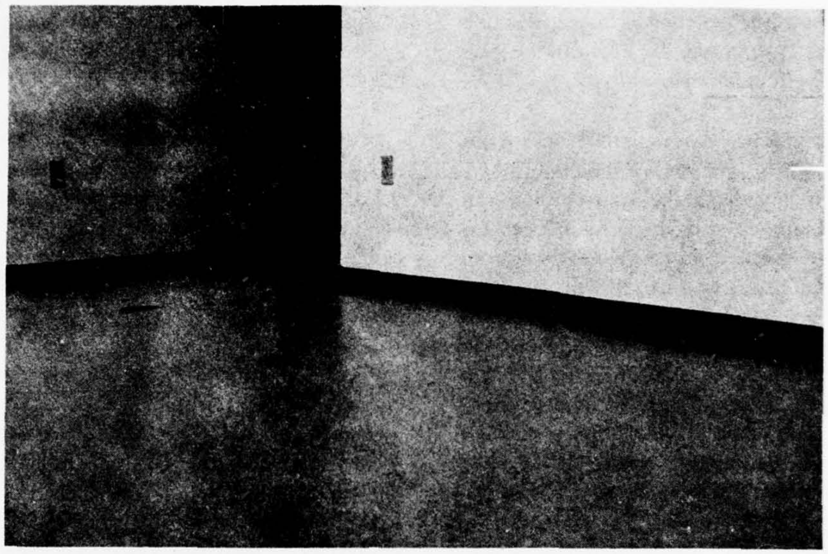

Figure 14. Recommended flooring example.

Summary and Recommendations

1. A raised-floor system should be used whenever possible for both permanent and temporary buildings.

2. If on-grade floor systems are required, a 4- to 6-mil polyethylene vapor barrier should be placed between the floor slab and a 4- to 6-in. (10 cm to 15 cm) gravel base course to prevent or reduce moisture coming up from the ground.

3. Joints should be provided between floor and wall systems to allow free movement for thermal expansion or contraction.

4. Concrete floors are recommended for permanent buildings. Pressure-treated lumber and plywood are satisfactory for temporary buildings.

5. Cork tile, rubber tile, and linoleum should not be used in naturally ventilated buildings. In fully air-conditioned buildings, most floor covering materials can be used.

Exterior Walls

Design Considerations

Wall Types. Lightweight frame construction provides the best type of wall for naturally ventilated tropical buildings. The wall's primary function is to provide protection from the sun and rain. If shaded, such a wall system will heat very little and inside temperatures will remain very close to outside temperatures. If not shaded, the walls will heat considerably and cause the interior spaces to become uncomfortable. The drawbacks to this type of wall system are reduced security and poor noise insulation.

More substantial wall types, such as masonry and concrete, will undoubtedly be required for certain building types. Cavity and solid-wall construction, unfortunately, utilize building materials which have high heat storage or conductive capacities. To offset these undesirable characteristics these wall materials need to be insulated from the outdoor extremes if they cannot be shaded effectively. However, insulation alone will not be adequate because heat will eventually build up

Raised buildings are subject to higher wind loads than conventional buildings at grade level because of the higher exposed building surface. Hence, buildings using raised floors must be designed to insure adequate anchorage to the ground and stability between the individual panels and the foundations.

On-grade Floor Systems. Where raised floors are not feasible, on-grade floor systems are used. Slabs on grade, a floor system commonly used in the semitropical region of the CONUS, cannot be strongly recommended for other tropic regions because they create several problems. Since the floor slab is in direct contact with the wet ground, it will be likely to create moisture problems unless the slab is properly waterproofed and sealed. In addition, because there is no space between the slab and the ground, the building will receive more reflected heat from the ground, natural ventilation cannot be fully utilized to cool the building, and it will be more difficult to control infestation by subterranean termites.

Construction Practices

Moisture Control. Floor systems in tropical regions are exposed fairly often to highly humid air and moist soil conditions. Raised floors should have very few moisture-related problems. To reduce the amount of moisture that may come up from the ground when a slab-on-grade system is used, a 4- to 6-mil polyethylene vapor barrier should be placed over 4 to 6 in. (10 cm to 15 cm) of gravel, which is placed on top of the soil. The gravel serves as a capillary break to stop groundwater flow, and the vapor barrier is used to stop water vapor from rising. Special consideration should be given to insuring that the floor/wall joint detail is watertight, as that area is one in which sealing problems commonly occur.

Insulation. Insulation in the floor system of a naturally ventilated tropical building provides no real benefits. For air-conditioned buildings, insulation is required. The size and type should be determined by the HVAC designer.

Expansion Joints. Interior floors are not subject to the same heat extremes as the roof and the walls; therefore, separation joints are needed between the floor and the wall systems to allow for thermal movement.

Material Usage

General. In fully-air conditioned buildings, any of the common flooring materials may be used. In naturally ventilated buildings fewer choices are available because of the problems of humidity, dirt accumulation, and pests. For reasons of hygiene, only easily cleaned materials as shown in Figure 14 should be used for floor finishes. The following sections list and discuss the best materials for naturally ventilated buildings.

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[7] *Materials Criteria for Construction in Tropical Environments*, NAVFAC INST 11012.98A (Department of the Navy, 1967), p 22.

in the wall materials and some of it will radiate into the interior spaces. Since air temperatures in the tropics remain fairly constant, it is very difficult to remove this stored heat by natural means.

Wall Openings. Extensive ventilation is required for nonair-conditioned buildings because of the constantly high temperature and humidity levels. In some tropical areas up to 90 percent of the wall areas of a building have been used to achieve acceptable air movement through habitable spaces.[8] To provide good cross-ventilation, buildings need to be properly oriented to the prevailing winds and designed to encourage airflow through the building. Building orientation was discussed in the planning section, "Climatic Constraints." Cross-ventilation is physically encouraged by several means. Building forms which are elongated perpendicularly to the wind (as shown in Figure 15) increase the internal airflow. Where an elongated shape is not practical, a U-shaped or rectangular form with central courtyards is recommended. Figure 16 shows how the central space serves as an outlet vent to produce the needed ventilation.

The position of wall openings is all-important in establishing an effective airflow, as shown in Figure 17. The following diagrams show how the vertical positioning of wall openings changes the airflow pattern. Where possible the openings should run from floor to ceiling and be fitted with adjustable sashes.

Operable panels, canopies, and louvers all provide control over the penetration and direction of air currents. Operable panels can be made of a glazed or opaque material. Since glass transmits heat so readily, its use should be kept to a minimum. Capturing and directing winds parallel to wall openings is best accomplished by operable casement panels. Awning type panels should be used low in the wall for inlets, and hopper or reversible pivot types should be used for outlets and high inlets. Canopies and overhangs are used for rain and sun protection, but they also influence the airflow. It has been found that by leaving a gap between the wall and the canopy, a downward airflow will occur, as shown in Figure 18.[9]

[8] B. S. Saini, *Architecture in Tropical Australia* (Melbourne University Press, 1970), p 29.

[9] O. H. Koenigsberger, et al., *Manual of Tropical Housing and Building, Part One: Climatic Design* (Longman, 1973), p 126.

External louvers may also present airflow problems. Because they are typically designed to slant outwards for weatherproofing, an upward air flow is caused. If louvers of this type are used they should be placed low in the wall and kept to fairly flat angles, as shown in Figure 19.

Weatherproofing problems arise when protection from wind-driven rain and maintenance of good airflow are required simultaneously. The use of unprotected adjustable panels and louvers to maintain an airflow in storm conditions has not proven satisfactory. Only through the use of large overhangs and high vents, or overhanging covers for lower vents, can air movement occur and the exterior remain dry (see Figure 20).

Shading Devices. Walls can be protected from the sun through the use of horizontal, vertical, or egg-crate devices. Horizontal devices are typically roof and floor overhangs and are effective at providing shade on the north and south walls. Vertical shading devices are less frequently used and usually take the form of end and screen walls. They are effective at shading east and west wall areas from the early morning and late afternoon sun. Figure 21 shows how both horizontal overhangs and vertical screen walls can be used effectively to provide shade. Egg-crate devices, a combination of horizontal and vertical shades, are used to provide shade for any orientation. Since the design of these devices is dependent on site conditions, the building form, and other parameters, a detailed explanation is beyond the scope of this report.

Construction Practices

Surface Treatment. The finish of an exterior wall determines to a great extent the amount of solar heat that the wall will absorb. A light-colored surface (e.g., a white painted wall) reflects 75 percent of the solar radiation which strikes it, whereas a slightly darker surface (e.g., one painted light gray) reflects only 25 percent. The more a building is like a mirror (85 percent - 90 percent reflective), the more efficient it is in reducing solar heat gains. However, this concept cannot be directly applied to where buildings are grouped because the reflected heat and light from these buildings will cause excessive glare and locally overheated ground and air temperatures.

Because of humidity variations between the inside and outside, vapor barriers should not be used in the external walls of nonair-conditioned buildings. The use of porous paints (emulsion type) is recommended to keep moisture from accumulating on the inside face of

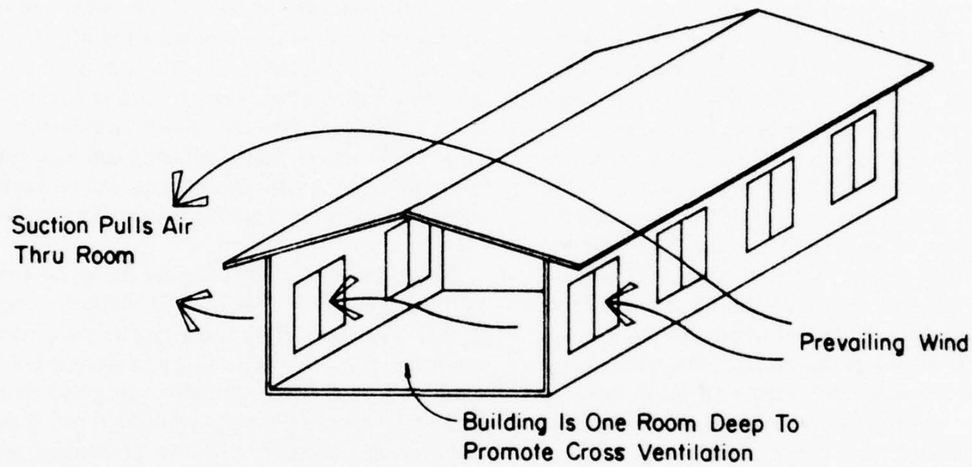

Figure 15. Cross-ventilation technique.

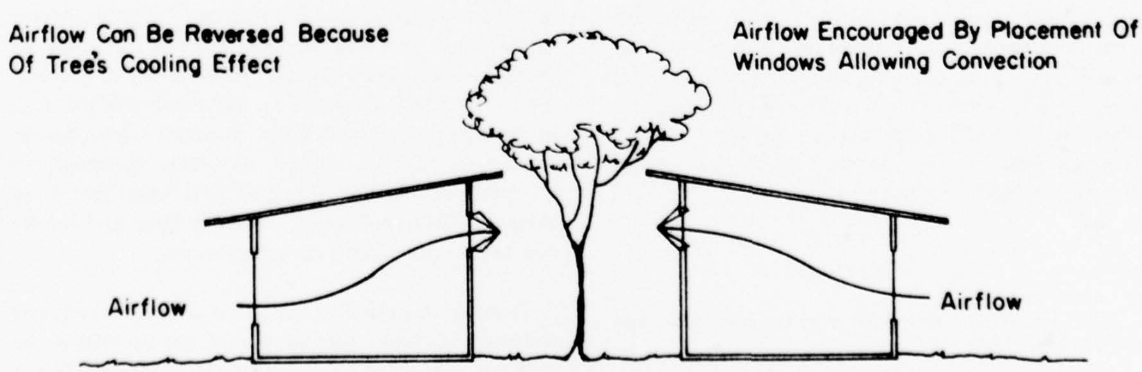

Figure 16. Courtyard ventilation.

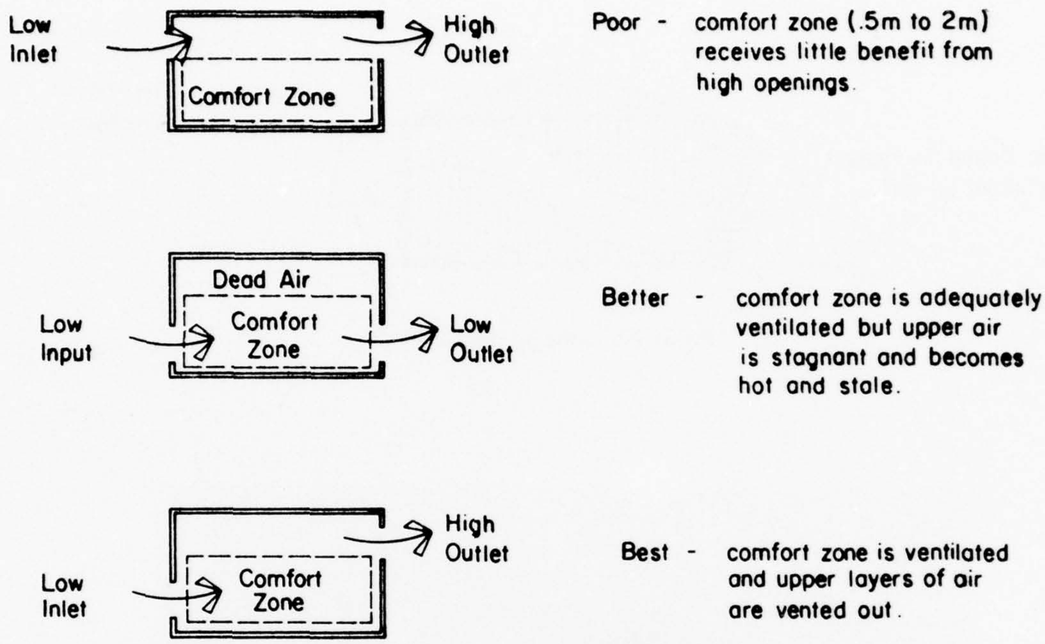

Figure 17. Wall opening placement.

Figure 18. Overhang design.

Figure 19. Louver positioning.

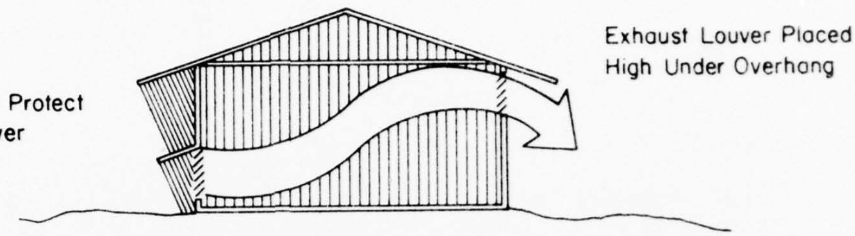

Figure 20. Overhang placement.

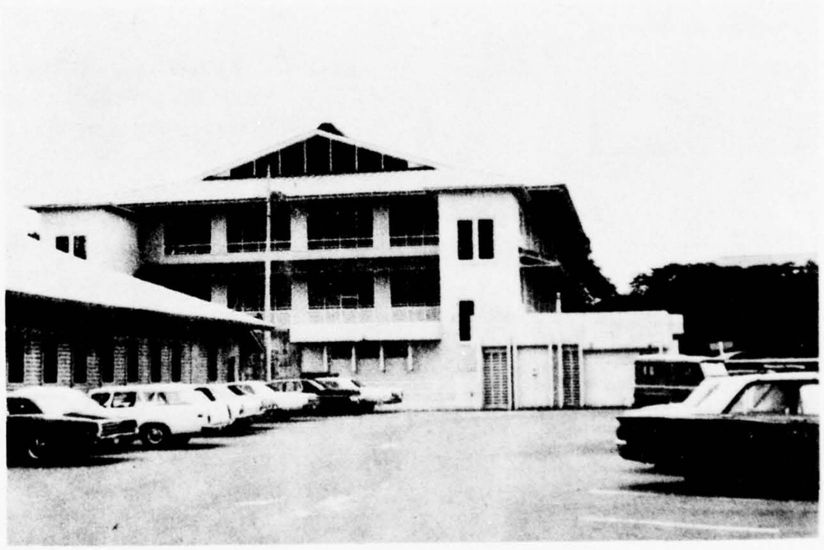

Figure 21. Overhang example.

the paint film, forming blisters, and causing the paint to peel off. Air-conditioned buildings, however, require a vapor barrier at the inside face of the wall section. Without one, walls quickly pick up moisture and severe peeling occurs, as shown in Figure 22.

Wind Considerations. High winds are common in tropical areas, and their effects on the wall system of a building can be disastrous. The wall system must be well tied together and adequately supported by the roof and floor systems. The use of transverse shear walls is highly recommended in buildings with wall openings occurring on one or two building faces. The use of a continuous bond beam is also recommended as it provides the wall with lateral support. Buttresses or pilasters may be required to stiffen longer walls. Protruding wall elements such as parapets or sun screens are particularly vulnerable to wind damage and should be well anchored.

Pest Control. The numerous mosquitos and flies in tropical regions cause discomfort as well as health problems. Buildings must be protected against them. Screening materials need to be strong, rustproof, and durable. Nylon netting is typically used and is very durable. Unfortunately, it restricts the airflow from

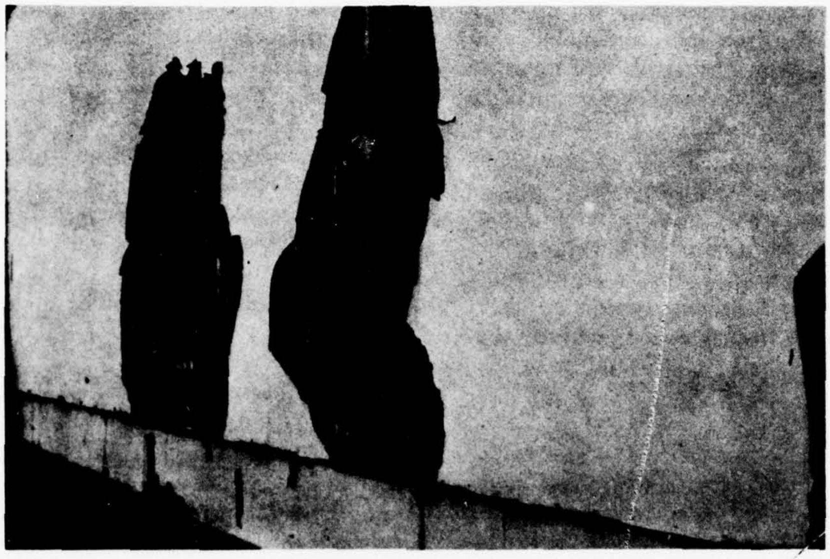

Figure 22. Peeling paint.

35 to 70 percent depending on mesh size. Because of this reduction in wind speeds, openings need to be as large as possible. Operable openings in air-conditioned buildings also need insect protection. Doors must be fitted tightly into their frames and thresholds to prevent any gaps through which insects may enter. Termite attack on the wall system can be prevented if the measures outlined in the previous section on foundations are followed.

Insulation. Wall insulation may be used in nonair-conditioned buildings within any walls that are not to be shaded, typically the east and west walls. Insulation must be used in air-conditioned buildings to limit the heat gain as much as possible. The amount of insulation needed will depend on the individual application.

Material Usage

Structural Wall Members. Concrete is a suitable material for wall construction of air-conditioned buildings. However, it is not a suitable material for naturally ventilated buildings except those that can be properly shaded because it has a large heat storage capacity. Other problems can also arise with the use of concrete. Humic acids can damage concrete near the ground unless it has been protected by bitumen paint. Concrete walls are subject to algae growth, as can be seen in Figure 23, especially exterior wall surfaces of air-conditioned spaces. Walls can be protected by use of a silicone resin sealer or by a chemical wash (1 percent copper sulfate solution, followed by a wash with 5 percent soap solution).

Concrete masonry is similar in most respects to poured concrete and is subject to the same restrictions. It is a satisfactory wall material in tropic environments except that its porosity may cause some problems. Masonry units should be well vibrated to reduce porosity and, when possible, autoclave cured to reduce shrinkage. Weep holes should be provided over bond beams and other solid precast members in all exterior hollow block walls. These holes will allow infiltrated water to drain to the outside. The effects of water infiltration can also be reduced by exterior surface treatment. Suggested treatment is given in the section on paint and coating.

Stabilized earth can be used for wall construction where local soils are suitable. Adobe walls can be constructed by making adobe bricks, setting them in place,

and plastering over them with a layer of soil cement. Rammed earth walls are constructed using soil stabilized by a binder (usually between 3 and 20 percent of the soil volume is cement, bitumin, resin, or other simple binder depending on soil composition). Soil is then tamped into a set of movable wall forms. If properly stabilized, the earthern walls are weathertight and resistant to pest infiltration.

Frame walls are used to support exterior and interior cladding materials best suited for tropical conditions. Restrictions on frame construction are few. Wood used for framing must be pressure treated. When both metal framing and cladding systems are used, either the cladding and framing should be of the same material or suitable insulating materials should be used to prevent corrosion problems.

Cladding. Galvanized sheet-metal siding has proven acceptable if covered with a protective coating. Unprotected sheets corrode rapidly under tropical conditions. See the Paints and Coating section for specific coating recommendations. Poorly detailed horizontal joint will also cause the metal panels to corrode rapidly as can be seen in Figure 24. To prevent this type of problem, a drip should be provided along the bottom edge of the upper panel as shown in Figure 25. This device will prevent water or moisture from becoming entrapped along the joint between the panels.

Aluminum sheet metal with a minimum thickness of 0.032 in. (0.8 mm) (20 gage) is suitable for use as wall cladding. However, contact with more noble metals (steel or copper for example) or with plant acids (overripe fruit, etc.) will cause corrosion and should be avoided. Anodized aluminum has greater corrosion resistance, an extremely good reflectance value (85 percent initially and 50 percent after weathering), and offers color variety. Thickness of the anodizing treatment varies from 0.0004 to 0.001 in. (0.01 to 0.025 mm) depending on the local climate's corrosion potential. The siding should be securely attached with aluminum or stainless-steel fasteners.

Baked-enamel sheet metal has recently emerged as a very durable wall-cladding material for use in tropical locations. Care must be taken to protect the enamel finish, as it prevents the metal from corroding. The finish requires very little maintenance, and panels come in a variety of colors.

Asbestos-cement sheet siding is well suited for tropical use. It is particularly resistant to corrosion. However, since its surface is prone to algae growth, it requires periodic washing with a copper sulfate solution. Since asbestos cement is a very brittle material, it cracks and punctures easily and thus should not be used on structures subject to moving or racking. Similarly, asbestos-cement shingles should not be used as cladding since they are easily broken (see Figure 26).

Corrugated fiberglass is an excellent cladding material but should be backed by an interior surfacing material such as hardboard or plasterboard. The backing is needed for structural support and acoustic insulation. Other types of plastic panels vary in durability and their long-term performance in the tropics needs to be tested further.

Stucco provides an adequate external wall covering for tropical locations. The construction, however, is time consuming taking 21 days to complete. The exterior surface is subject to algae growth and requires treatment similar to that used for concrete walls. If exposed to intense sunlight and rain, crazing may occur because of differential shrinkage and expansion. An advantage of stucco finishes is that they are easily patched; however, an incomplete patch such as that shown in Figure 27 offers very little protection and should not be allowed.

The suitability of pressure-treated wood panels as a wall cladding material has not yet been determined. The fungus and molds that thrive in the hot, humid climate weaken wood, and the rotting process is accelerated. Exposure testing is needed before recommendations can be made. Wood siding should definitely not be used unless it is pressure-treated to prevent termite attack and to retard decay. Figure 28 shows a building in the Panama Canal Zone whose siding has been badly rotted and damaged by termites.

Wall Opening Inserts. Clad aluminum alloy screen has proven satisfactory for general use. In more corrosive environments vinyl-coated aluminum, fiberglass, or nylon screens are best suited. Nylon is a recommended screening material, but it is subject to shrinkage and punctures and it burns. Fiberglass is much stronger, more fire resistant, and does not shrink. Screens should be of a number 16 or 18 mesh, and perimeter splines should be used to hold the screen into the frame.

Glazing. Single-pane reflective glass is typically used for nonair-conditioned buildings. It should be properly shaded because of the large amount of heat that unshaded single-pane glass transmits. The use of reflective

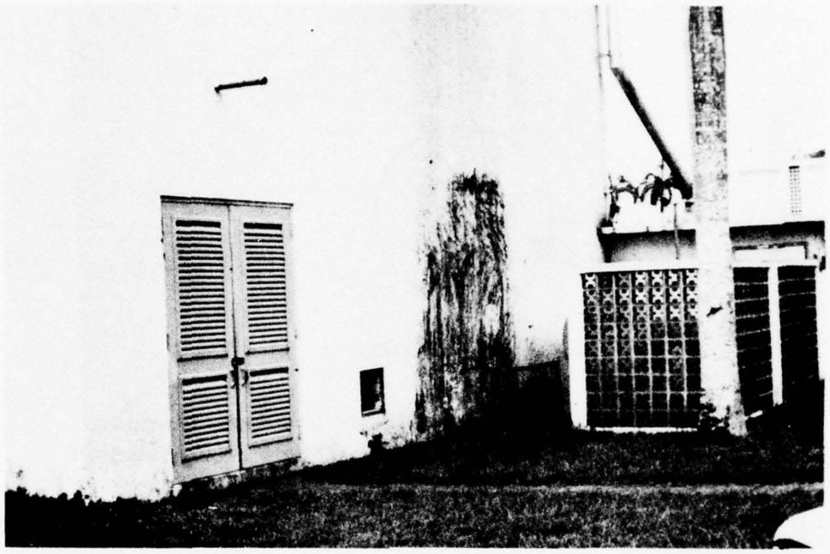

Figure 23. Mold growth.

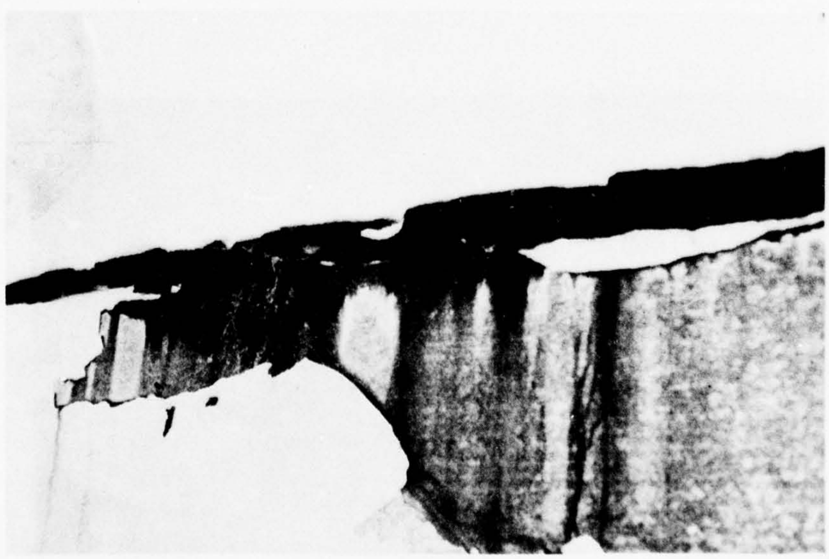

Figure 24. Galvanized metal deterioration.

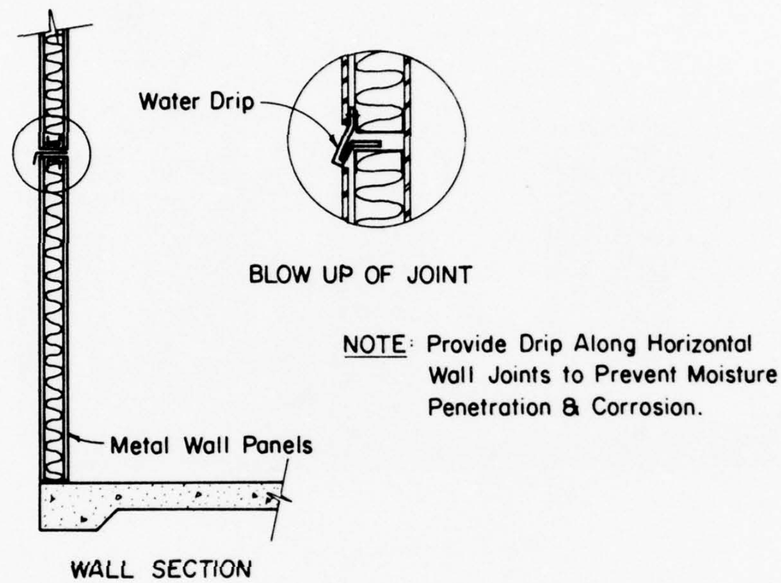

Figure 25. Recommended metal-panel joint design.

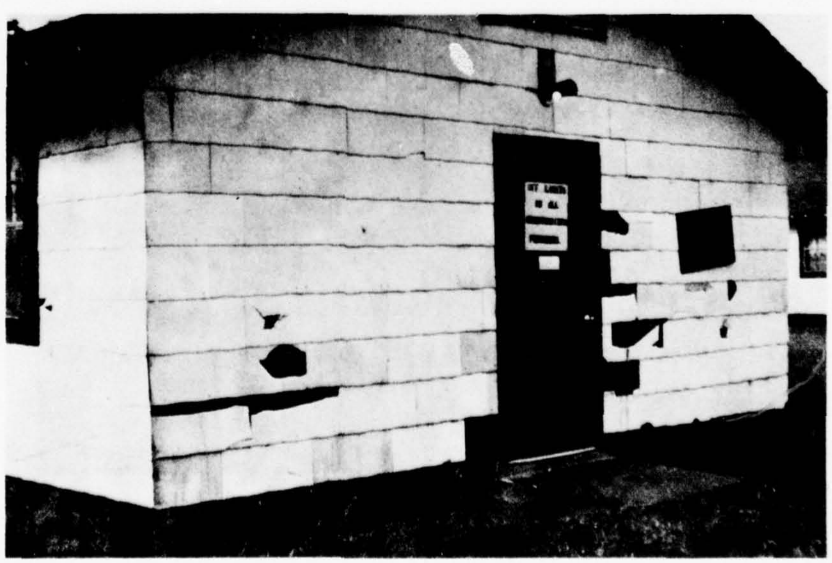

Figure 26. Asbestos-cement shingle crackage.

Figure 27. Poorly patched stucco.

Figure 28. Deteriorated wood siding.

double glazing is recommended for air-conditioned buildings to minimize heat transfer. Glazing is subject to mold growth and so must be periodically cleaned.

Doors. Sheet glass and properly-protected metal-clad doors are acceptable and commonly used in the tropics. Metal doors should be equipped with overlapping seals on the door frame to prevent the entry of moisture. Pressure-treated wooden doors are acceptable, but their durability may be limited.

Louvers. The best materials for ventilation louvers are stainless steel, aluminum, glass, and fiberglass. Wood, unless pressure treated, should not be used.

Summary Recommendations

Permanent Buildings. The use of lightweight wall systems is highly recommended for permanent facilities. Their advantages are speed of assembly, durability of materials, and ease of placing wall openings in the panels. Although concrete and concrete masonry are also suitable for wall construction, they are not the best materials to use unless they can be properly shaded because of their high heat-storage property. The external wall color should be very light and reflective if the building is fairly isolated but should be a more subdued tone if the building is in an urban setting. If the building is to be air conditioned, insulation, double glazing, and adequate weatherstripping around all wall openings will be required.

Theater-of-Operations Buildings. Lightweight frame walls are especially suitable for temporary construction. Pressure-treated wood is a good framing and cladding material because it is easily assembled, simple to repair, and should not deteriorate during the short use cycle. Glazing should be used sparingly, if at all. Instead, screened openings with plywood cover panels are suggested for general use. Fixed louvers are recommended over adjustable ones because they require much less maintenance. The external colors should be light whenever possible.

Roofs

Design Considerations

Roofing systems are subjected to the most significant environmental stresses of any component of a building in the tropics. The tropical roof must provide adequate protection from intense solar radiation, occasionally destructive winds, intense periods of precipitation, and the growth of fungi and mold resulting from high relative humidity.

The ultimate purpose of the tropical roof is to insure that the radiant heat gain to the building interior does not increase the interior temperature above that of the exterior air. The roof's exterior surface must therefore have a high reflectance value as well as high resistance to intense solar radiation and humidity.

Construction Practices

The initial concern in the design of a tropical roof is direct and reflected radiation. High reflectivity of the outermost roof surface will insure that not all of the solar radiation is absorbed in the roof materials and transferred to the building interior below. The color, surface structure, and age or condition of this layer will determine the intensity of radiation reflected. Abundant evidence suggests that metal roofs or those of a color approaching white are most effective.[10] New aluminum sheeting has the highest reflectance value and is closely followed by whitewashing of other surfaces. Whitewashing is the simplest method, although it involves periodic maintenance, while aluminum sheeting is expensive and its high level of reflectivity decreases with age. In addition, the net heat gain for white surfaces is lower than for aluminum.

In addition to using a highly reflective outer surface, heat gain can be prevented by installing a second protective layer as a ceiling. In effect, a double roof is created as shown in Figure 29. The air space between is ventilated to carry out heat by convection. The depth of this space must be great enough to insure sufficient air movement and to provide access for inspection and maintenance. This lower level or ceiling is an appropriate location for insulation. Aluminum foil placed over the insulation is also effective in reflecting heat which has penetrated the outer roof. One performance specification of interest states that the ceiling temperature should not exceed the air temperature by more than 7°F (4°C). To achieve this temperature, insulation with a U value of 0.56 BTU/hr-ft^2 deg F (1.5 W/m^2°C) should be used. The equivalent resistance (R=1/u) is 1.78. This amount of insulation required is negligible. For example, the resistance of 3/4-in. (1.9 cm) acoustical tile is 1.78, and that of 1-in. (2.54 cm) cellula glass is 2.44.[11] Insulation at the second level is used to prevent absorbed heat from

[10]G. Lippsmeier, *Building in the Tropics* (Verlag Georg D. W. Callwey, 1969), p 165.

[11]C. G. Ramsey and H. R. Sleeper, *Architectural Graphic Standards* (John Wiley and Sons, 1970), p 320.

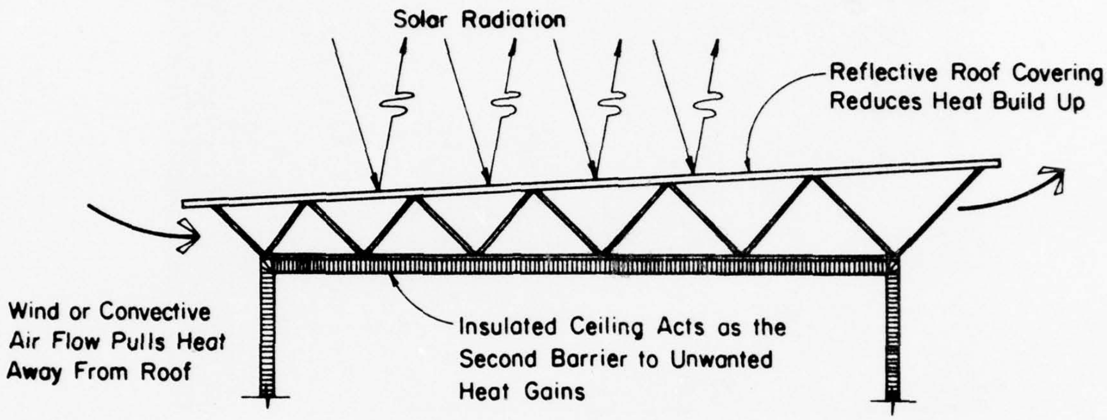

Figure 29. Double roof concept.

entering the interior. Insulation should not be installed in the outer roof because it may cause higher roof temperatures which would damage roofing materials and speed their deterioration.

Roof eaves can also be employed effectively to reduce heat gain through the walls. They will also keep rain off of windows and walls and will provide additional shade. To be effective, the eaves should project at least 4 ft (1.2 m) beyond the wall.

The slope of the tropical roof is the second major concern. The outer roofing layer must be selected to shed water effectively. Also as Figure 30 illustrates, a roof with a low slope can become covered with debris. Roof slope plays an important role since the greater the slope, the greater the runoff speed.

Joints in the outer layer of the roofing material must be successful in preventing wind-driven rain from entering the building interior. Movement of the outer layer at the joints must also be considered. Thermal shock due to sudden temperature changes (for example, during rains) and expansion due to high temperatures require fairly flexible roofing materials and connections. Movement of the roof must be accepted so that cracks, breaks, and joint failures do not permit water damage.

During intense rains, the runoff rate is an important consideration because, unless protected, the ground and foundations will be subject to erosion. Concrete aprons or gravel should be installed below eaves. Gravel may be a better choice since the fairly intense winds during tropical rain storms can drive spray from rain hitting the apron up onto the exterior wall and cause weathering problems. In the tropics gutters often create more problems than they solve. High runoff rates can overflow or overburden the gutter. Also, if improperly installed, gutters will collect debris and promote the growth of organic material which can further clog the gutter and cause corrosion, or attack other roofing materials (see Figure 31).

The roof slope and the building orientation limit the amount of radiation hitting the roof surface. The angle of incidence of sunlight to the roof and the intensity of direct solar radiation can be calculated for specific climates and locations to provide a method for determining an optimal roof slope which minimizes heat gains. Unfortunately, there is some concern that slope and orientation are not so important when total incident solar radiation (not only direct radiation but also that from the sky and ground) is considered. Tools for the design of tropical roofs are available.[12] Flat roofs

[12] G. Lippsmeier, *Building in the Tropics* (Verlag Georg D. W. Callwey, 1969).

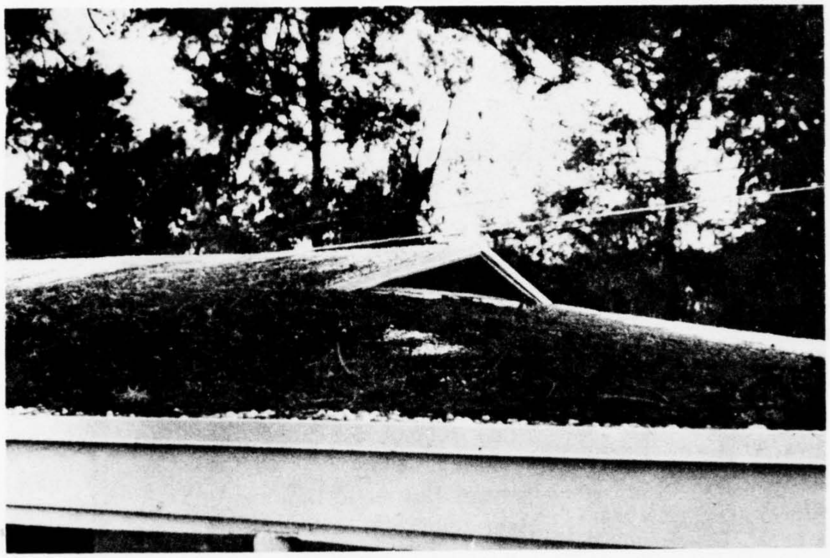

Figure 30. Debris-covered roof.

Figure 31. Grass growing in roof gutter.

should be avoided because of the greater angle of incidence of radiation, low runoff rate, and potential ponding problems.

Wind action on the roof is the third design concern. Wind speed is generally low in the tropics and the direction is fairly constant. During the rainy seasons, however, wind speeds may become very high. Tropic roofs should be designed to resist uplift or suction forces, impact loads from flying debris, and racking movements which can loosen connections or shatter certain brittle roofing materials.

To reduce the potential for damage to tropical roofs, the designer must have at his disposal an accurate assessment of anticipated wind loads for the building site. The roof can then be designed to resist these loads. A better solution based on the occasionally unpredictable nature and intensity of tropical storms is to design the roof to partially fail to relieve pressure concentrations. In the latter case eaves can be designed to be folded down, stored, or tied down during storm warnings.[13] Other roofing materials at the building perimeter can be designed to break away, creating a vent which reduces losses to the remainder of the roof.[14] Another concern is the gable or end wall roof connections. Loss of the gable wall due to suction results in high positive pressures beneath the roof. In combination with suction, this accumulation of forces can result in severe damage. Connections at the gable wall must be carefully considered.[15] Structural connections that connect the foundation, floor, wall, and roof are typically called cyclone bolts. Cyclone bolts provide a dependable connection and should be used in high wind areas (see Figure 32).

Material Usage

Sheet-metal roofing finds wide acceptance in the tropics because of its reflectivity, economy, and ease of handling and transport. Corrugated galvanized iron (CGI) has been widely used, but its use should be limited to temporary construction. It is not recommended for use in permanent construction because corrosive elements in tropical environments, especially near seacoasts, cause fairly rapid deterioration of the surface. When CGI is to be used, the minimum thickness should be 24 gauge. The metal must be coated after installation. Joints where CGI sheets lap should be coated or sealed with bituminous material. Joints in roofing should be lapped a minimum of two corrugations.

Aluminum sheeting is a more successful alternative when increased material cost is acceptable. The minimum thickness is 18 gauge. Although new aluminum sheeting is highly reflective, it does age, and reflectivity will be reduced by up to 50 percent without periodic maintenance and cleaning. Sheet metal which has been coated with a baked enamel coating is also reported to serve satisfactorily as long as the coating has not been broken or damaged. Availability, however, may be a problem.

Sheet or corrugated metal roof surfaces can serve quite effectively with suitable inspection and maintenance. An added advantage is that metal is resistant to impact loads from falling debris during tropical storms. It is suggested, however, that battens be used over the metal to insure that connections will not fail during storms. Finally, noise can be a problem with metal roofs. Rain, wind, or debris striking a metal roof may be disturbing unless noise insulation is provided.

Plastics are gaining increased acceptance in tropical climates, but little evidence is available to qualify this acceptance.

Metal fasteners and timber connectors corrode rapidly in a tropical environment. Galvanized steel fasteners are an acceptable alternative, athough cement-coated nails and tempered aluminum nails can also serve successfully. Fasteners should be of the same material as the roof to prevent galvanic action. Otherwise, they should be properly insulated to prevent direct contact.

Cast-in-place concrete is a difficult material to work with in the tropics. In addition, it is not appropriate for roof construction because of its high heat storage properties. See the section on concrete in Chapter 5 for further information on the use of concrete in tropical regions.

Good quality asphalt shingles have been used successfully in the past. Light-colored shingles should be selected to increase reflectivity.

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[13] W. F. Reps and E. Simon, *Design, Siting, and Construction of Low-Cost Housing and Community Buildings to Better Withstand Earthquakes and Windstorms*, Building Science Series 48 (National Bureau of Standards, 1974).

[14] K. J. Eaton and J. B. Menzies, *Roofs, Roofing and the Wind*, Bulletin CP 75/74 (Building Research Station, Garston, Watford, England, 1974), p 3.

[15] Eaton and Menzies, p 3.

Figure 33. Grass growing in built-up roofing.

or whitewash should be used to increase reflectivity. Finally, battens should also be considered as a defense against strong winds.

When a built-up roof is to be installed, the most significant step toward insuring satisfactory performance is thorough inspection of workmanship and materials. Many roofing problems arise as a result of insufficient care during installation when moisture is actually trapped in the membrane. The roof deck and all materials must be absolutely dry.

Insulation, when desired as part of a tropical roofing system, should be capable of retaining its insulation properties when wet. Closed-cell insulation, cellular glass or expanded perlite are recommended.[17]

Any lumber used in roof construction should be treated to resist moisture, organic decay, and termites. The roof should be designed to insure that the lumber can dry rapidly. When painting is a requirement, it should be deferred until the dry season and then done only when the moisture content of the wood is 20 percent or less. Varnishes, oils, and stains have little value in treating unprotected wood against decay.[18]

Both aluminum or copper flashings have worked well in tropical locations as long as fasteners of the same metal are used. The perimeter of the roof must be securely held down by flashing because high winds will pull up any loosely attached roofing. Typically, expansion construction joints are difficult to seal effectively (see Figure 34). Butted joints with a cover plate (Figure 35) are prone to leak because of faulty workmanship or excessive movement. An alternative to the butt joint has been suggested which eliminates one edge of the joint and should be much easier to seal (see Figure 36).

Metal flashing for temporary buildings is typically uneconomical. In lieu of metal flashing, roll roofing may be terminated by carrying the felts around the edge blocking as shown in Figure 37.

[17] *Materials Criteria for Construction in Tropical Environments* (NAVFAC INST 1102.98A, 1967), p 20.

[18] *Materials Criteria*, p 44.

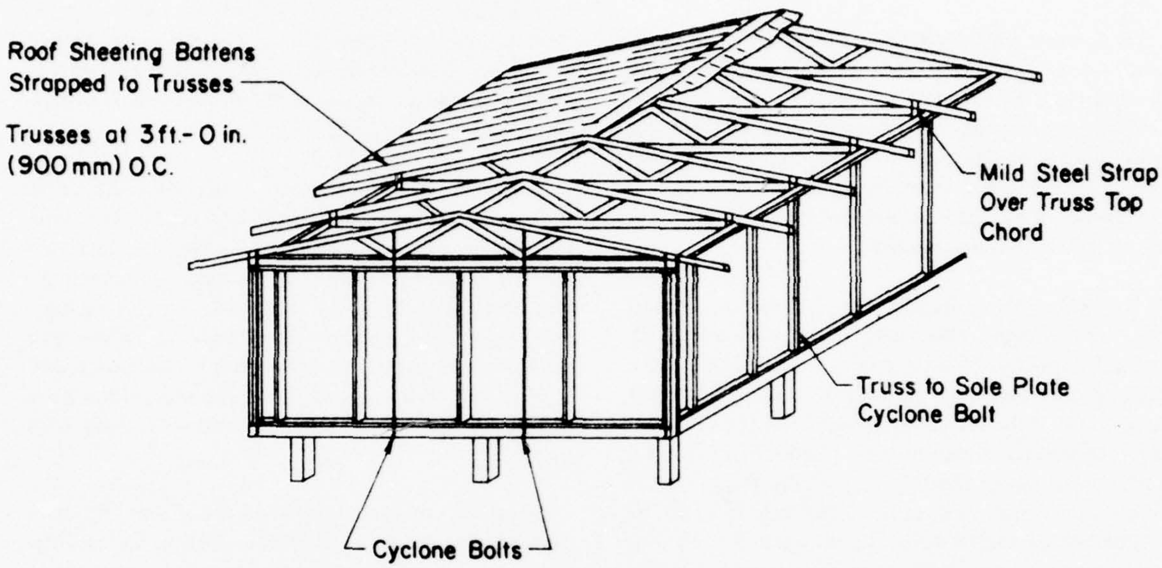


Figure 32. Cyclone bolt illustration.

Asbestos-cement panels and shingles have met with success as roofing materials in the tropics. The material is economical, easy to install, and weather and corrosion resistant. Disadvantages include brittleness, high breakage rates during transport, sensitivity to sudden stresses, and discoloration due to aging. Roof panels require a rigid frame because movement and stresses transmitted to the material will cause it to crack. The normal gray surface will require whitewashing to increase reflectivity.

Clay tile is not recommended. The joints are difficult to seal against leaks. The material is brittle and subject to breakage during transport and under the impact of wind-driven debris. Breakage of the tiles during storms contributes to debris which can be harmful to persons or buildings. Tile may also break when used over an air-conditioned building due to heat stress from an overheated exterior and cool interior if the roof is not well insulated.

Plastics are gaining increased acceptance in tropical climates, but little evidence is available to qualify this acceptance. Some available information suggests that fiberglass-reinforced translucent panels are unsatisfactory because of their tendency to discolor and their high heat absorption. Other forms of plastic tend to warp and crack as they deteriorate when exposed to rapid temperature changes and ultraviolet radiation.

The use of built-up roofing in the tropics is not a recommended practice. Bitumen hardens, cracks, and crumbles under intense solar radiation. Felts blister under high humidity conditions. Because of their lower slope and slower runoff rate, built-up roofs accumulate dirt and seeds which can grow, attacking the roofing (Figure 33). Gravel not firmly embedded in the membrane also presents a hazard during high winds.

Although built-up roofing may not be desirable, it is still required for long-span, low-sloped buildings. In this case, the felts should be asbestos rather than organic to resist decay. The asphalt used should be of a high melting temperature type to resist softening and flowing which could result in nonuniform attachment to the felts. Gravel or other surfacing should be well embedded and loose gravel swept from the roof. In general, a mineral-surfaced cap sheet may be substituted for gravel to reduce the potential of damage from high winds.[16] An aluminum-based reflective coating

[16] *Material and Design Criteria for Construction in Tropical Environments*, NAVFAC Draft Report (Department of the Navy, January 1977), p 07500-2.

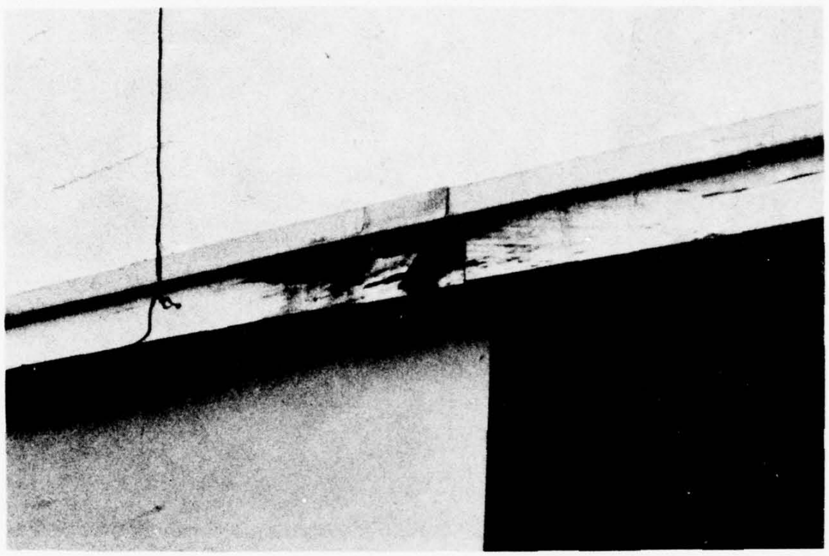


Figure 34. Rotted flashing detail.

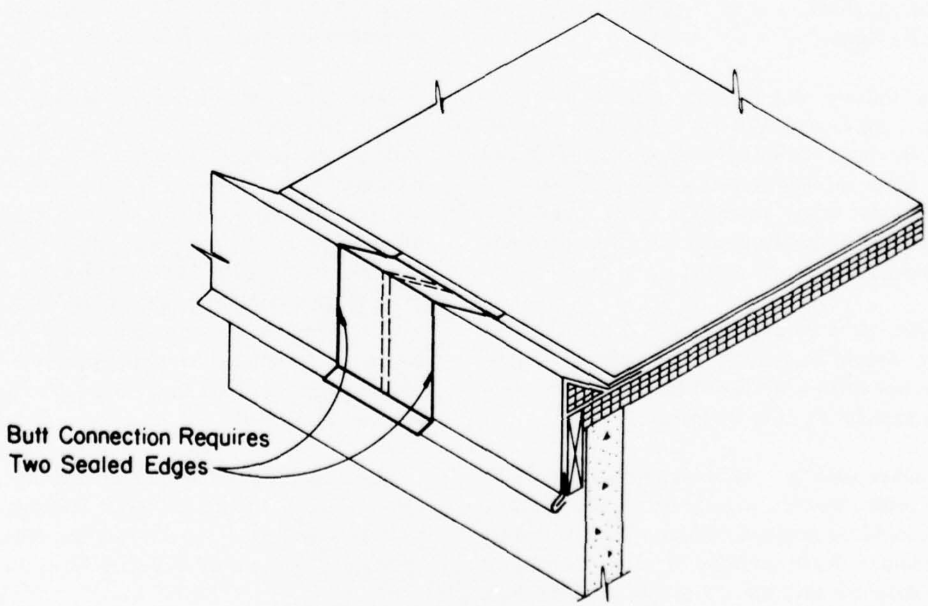


Figure 35. Butted flashing joint.

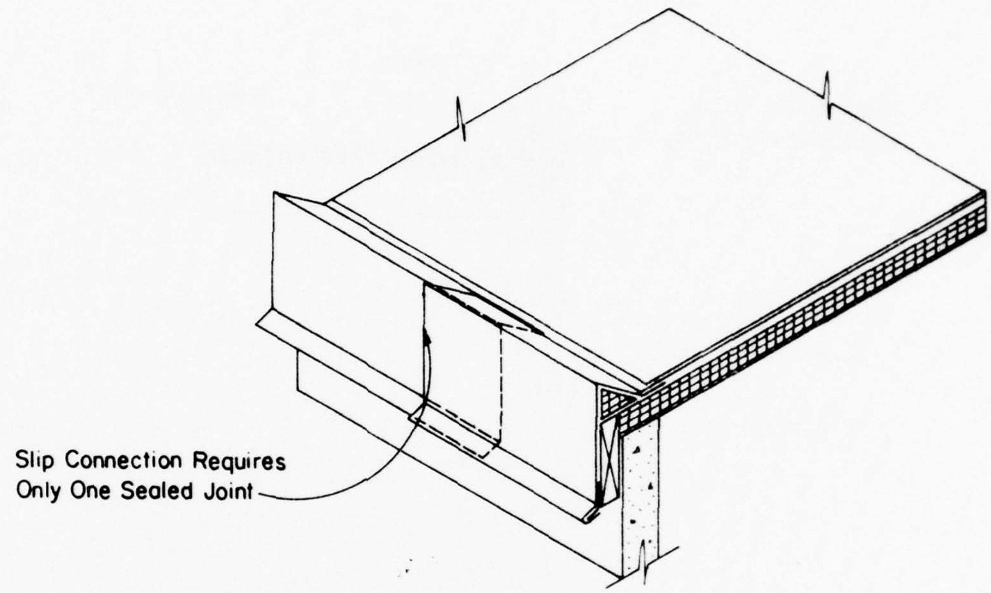


Figure 36. Slip flashing joint.

Summary Recommendations

1. The roofing system should be carefully designed to insure that heat gain does not result in interior temperatures rising above exterior temperatures.

a. The outer roof surface should be as reflective as possible.

b. Increased maintenance of the outer roof surface should be accepted.

c. Construction of a double-layer roofing system is recommended if justified by the comfort and activity requirements for each building.

d. The roof slope should be maximized and calculated based on building location and orientation to minimize the incidence of solar radiation.

e. The eaves should extend a minimum of 4 ft from the wall.

2. Erosion control below the eaves should be provided by a gravel splash guard.

3. Gutters are not recommended.

4. Roofing may be designed to fail partially at the roof perimeter under severe wind loads. This feature is particularly important when wide eaves are used. Alternatively, eaves should be capable of folding down along the wall, or of being removed and stored under threat of severe winds.

5. The end wall or gable wall connections in lightweight construction should be reinforced with full-wall-length cyclone bolts from foundation to roof.

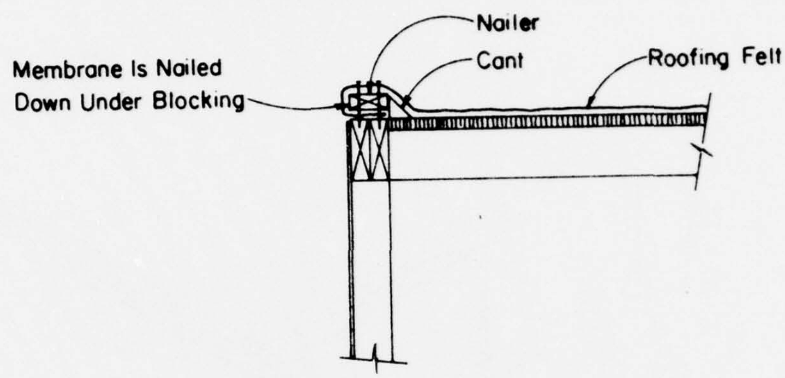
6. Asbestos cement and corrugated galvanized iron are recommended for the outer roof surface only if properly coated and regularly maintained.

Interior Walls

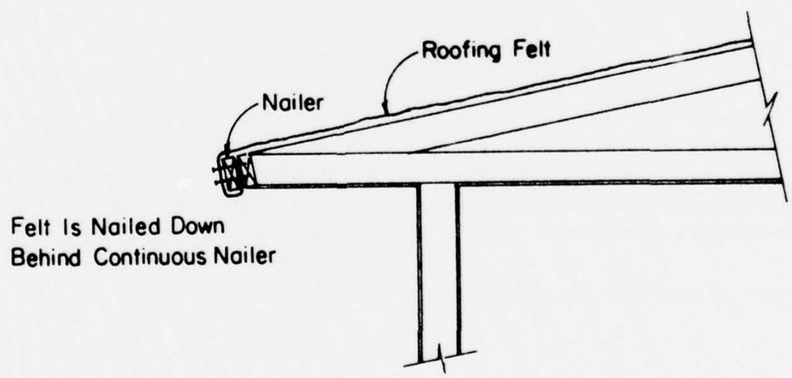
Design Considerations

Interior partitions are normally required for visual and acoustic privacy. In tropical buildings a conflict arises between privacy and comfort because the use of interior partitions obstructs the airflow significantly. As shown in Figure 38 the use of partitions creates pockets of still air which are very uncomfortable.

Where acoustic privacy is not critical and visual privacy is important, interior walls should be designed as

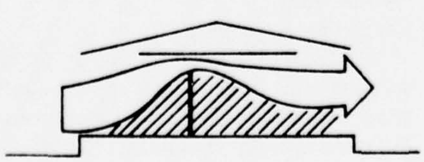


a. End wall detail.

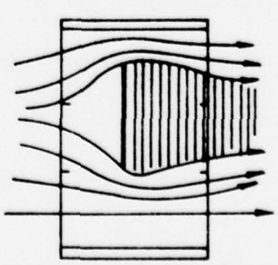


b. Roof eave detail.

Figure 37. Temporary building flashing details.



a. Effect of Vertical Partitions



b. Effect of Horizontal Partitions

Figure 38. Interior airflow.

screens which permit a sufficient air flow either through or around them, as shown in Figure 39.

Where acoustic privacy is required, buildings should be designed to be one room deep or mechanical ventilation or cooling must be used.

Construction Practices

Interior finish materials are prone to damage from exposure to rain or high relative humidity. They therefore must be stored in protected areas or carefully covered to prevent damage. More specific protection requirements will be listed in the material usage section later in this section.

Since there should be no direct light coming in through the windows, ceilings and interior walls should be finished in very light colors. The ceiling should be white to reflect and spread the indirect light evenly throughout the interior. Walls containing windows should be finished in white or a light gray to reduce the contrast between the bright window and the surrounding wall, thus minimizing glare. Interior partitions should also generally be light to reduce the amount of artificial lighting required during the day.

Sound-absorbent materials should be used whenever possible, but care should be taken when using organic materials as they are subject to decomposition in highly humid areas.

Material Usage

Portland cement plaster has a high susceptibility to shrinkage cracking and is not recommended in tropical areas. Gypsum plaster has held up satisfactorily if properly applied.[19] Metal lath must be galvanized because unprotected metal corrodes too quickly. Solid lath appears to be suitable as long as the wall remains properly sealed. The major problem with plastering in tropical areas is that the high humidity prevents the plaster from drying properly, causing a subsequent loss in strength. When plaster finishes are required, an artificial heat source or a dehumidifier should be used to reduce humidity problems.

Asbestos-cement wallboard provides a suitable interior finish where not subjected to mechanical damage. Gypsum board and fiberboard both tend to warp and swell in humid environments and are not durable enough for most uses. Particle board is susceptible to termite attack unless protected. It should also be avoided because of its high moisture absorbing property.

Finish lumber can be used for interior walls and finishes if properly treated, installed, and maintained in dry conditions. Since it can be damaged by termites it must be adequately protected or contain natural preservatives. Some of the native woods have good resistance to termite attack; using these wood species for construction may be feasible. Some of the important tropical species are listed in Appendix C along with their important characteristics and applications. Wood should never be placed in contact with the ground or allowed to become saturated with water.

Metal panels and partitions are relatively unaffected by the high humidity as long as they are properly coated. Plastics similarly have no restrictions as interior finishing materials except that they may be prone to termite attack.

Concrete is suitable for interior walls but is not recommended because of its heat storage capacity. Simiarly, exposed masonry walls are not recommended.

Mineral-core doors are not satisfactory for use in the tropics because they generally are not well sealed. The core absorbs moisture, swells, and causes the surface to rupture and swell.

Solid-core and wood-panel doors are satisfactory if they are treated and sealed. Interior metal-clad doors are also suitable if they are coated but require periodic maintenance.

Summary Recommendations

Interior wall construction should be similar for both permanent and temporary facilities. The walls should be lightweight (to provide a low heat-storage potential) and should offer minimum interruption to air flow. Interior colors should be light to reflect available natural light and reduce the need for artificial lighting, cutting down on the heat gain the lights cause. The main difference between permanent and temporary construction will be not the choice of the material but the quality of the finish. The use of rough-finished hardboard or perforated-metal panels are recommended because they have some acoustic insulating value.

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[19] *Materials Criteria for Construction in Tropical Environments*, NAVFAC INST 1102.98A (Department of the Navy, 1967), p 23.

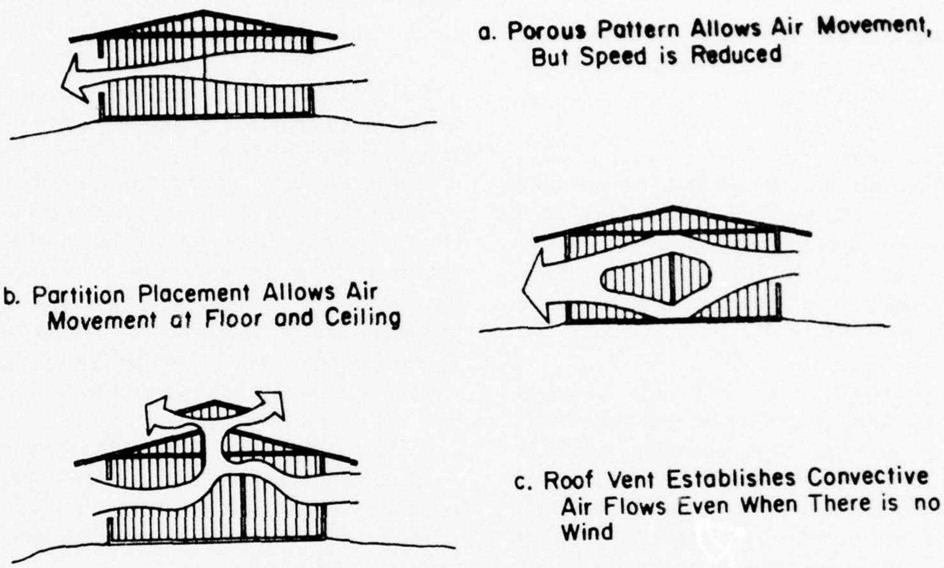

Figure 39. *Partition's effect on airflow.*

Building Hardware

General

Tropical conditions quickly cause unprotected building hardware to corrode. Ferrous metal hardware should not be allowed except for parts which require high strength. Such parts may be made of stainless steel (Type 316). All fasteners used with the hardware should be of a similar alloy to prevent galvanic action.

Material Usage

Door hardware is subject to high corrosion rates and, in exterior applications, dust accumulation from the prevailing winds. Where sheltered, cylinder locks provide good service if they are treated periodically with graphite powder. For exterior doors in exposed locations, mechanical locks do not hold up well; manual barrel bolts or foot-and-chain bolt closures should be used instead.[20] Nylon or teflon is suggested for all bearings and bushings.

Bronze and stainless steel (series 300) have both proven to be satisfactory window hardware materials.[21] Aluminum, as mentioned above, tends to "freeze up" and is satisfactory only if the moving parts are anodized or coated with teflon.

Venetian blinds are often used for sun and glare control in tropical buildings. Those made with coated aluminum slats work well. Blinds using polyvinyl cloride (PVC) slats are not recommended, as they deteriorate from exposure to sunlight. All hardware should be of a similar aluminum alloy. The tapes should be made of cotton because plastic substitutes have a tendency to shrink and deteriorate when exposed to sunlight. Cords and cord rollers should be made of nylon.[22]

Summary Recommendations

Because of the high corrosion potential, all hardware should be made of bronze, aluminum, or stainless steel (series 300). All fasteners must be of an alloy similar to the hardware proper. Moving parts such as cylinder locks will require periodic lubrication (with graphite powder). Where aluminum or stainless-steel parts are fastened to or bear on parts of the same alloys, protection must be provided to keep the parts from freezing together.

[20] *Materials Criteria for Construction in Tropical Environments*, NAVFAC INST 1102.98A (Department of the Navy, 1967), p 23.

[21] *Materials Criteria*, p 25.

[22] *Materials Criteria*, p 25.

Electrical Equipment

General

Material specifications must list all unusual service conditions, such as high humidity, moisture, salt spray, and insects, and should require equipment suitable for the environment encountered.

Fungus and moisture resistance for certain electrical components should be provided in areas with considerable moisture and high humidities. Equipment located within air-conditioned areas and/or equipped with internal heaters to provide a 50°F (10°C) minimum temperature differential above ambient are considered to be adequately protected.

Electrical components such as switches, fuses, contacts, oil-immersed transformer windings, and heater elements should not be treated. Other materials and components which are inherently fungus resistant or are protected by hermetic sealing need not be treated.

Circuit elements not covered above and which have a temperature rise of not more than 75°F (24°C) when operating at full load should be coated with a fungus-resistant varnish conforming to military specification MIL-V-173. The treatment method must be in accordance with military specification MIL-T-152. Circuit elements include but are not limited to cable and wire within an enclosure, switchboards, panelboards, switchgear, terminal and junction blocks, junction boxes, capacitors, and coils. Sample coated-metal panels should be tested in accordance with Method 6071 of Federal Test Method Standard 41.

Circuit elements such as motor coils, generator and dry type transformer windings, and similar electrical components which have a temperature rise exceeding 75°F (24°C) when operating at full load should not be coated with a fungi-toxic compound. Instead, such components should be given two coats of varnish conforming to grade CB and one sealer coat conforming to grade CB of military specification MIL-I-24092. The coats should be applied by the vacuum-pressure, immersion, centrifugal, pulsating-pressure, or built-up method so as to fill all interstices in the coils and preclude the entrapment of air or moisture. The sealer coat may also be applied by brushing or spraying. Panelboards, telephone cabinets, bus ducts, and switchgear must be nonventilated and, where possible, furnished without conduit knockouts or conduit and cable openings. Where ventilated equipment or openings are required, all openings should be provided with tight-fitting screens to prevent entrance of insects. Threaded hubs should be used where possible.

Interior Electrical Equipment

Equipment should be specifically designed and approved for use in the actual environment encountered. The following are typical special requirements for components:

1. Circuit breakers with bimetallic thermal elements must be treated to prevent corrosion or galvanic action, or they should be replaced with suitable sealed or protected solid-state tripping elements.

2. Wall switches and receptacles should be made of porcelain or of fungus- and corrosion-resistant plastic. The metal parts should be nonferrous. Dissimilar metals should not be used in direct contact or within 1/4 in. (6.4 mm) of each other or of the outlet box in which the device is installed.

3. Unit substations, switchgear, and motor-control centers should be equipped with thermostatically controlled heaters to maintain a temperature 18°F (10°C) higher than ambient inside the enclosure. The heaters should be connected to a separate source when equipment is deenergized except during equipment maintenance.

4. Motors larger than 1 HP or generators larger than 10 kW should be totally enclosed and equipped with a heater which is energized when the unit is not running. Alternately the motor or generator can be heated by energizing it with a suitable low voltage when not running.

Exterior Electrical Equipment

Equipment for exterior use should be specifically designed and approved for use in the actual environment encountered, taking into account the presence of insects such as roaches and termites. In salt-laden atmospheres, salt-spray tests should be conducted on all equipment in accordance with applicable military specifications unless certified test reports on identical equipment are furnished. The following are typical special requirements for components:

1. Oil-filled transformers should be hermetically sealed or equipped with an inert gas provided by a nitrogen cylinder.

2. Wood poles should be pressure treated and suitable for the local environment and insects. Where re-

quired, poles may be made of concrete, fiberglass, or aluminum.

3. Guys should be made of phosphor bronze, copperweld, or aluminum-encased steel if not subject to galvanic action.

4. Hardware should be made of silicon bronze, copper, aluminum-encased steel, or hot-dipped galvanized steel.

5. Crossarms should be made from pressure-treated wood selected for the local environment or from spun-glass-reinforced plastic.

6. Cables directly buried in coral backfill should be of the jute-protected, double-tape-armored type. All DB cables should be resistant to roach, termite, and microbial (soil micro-organism) attack.

7. Manholes and handholes should be designed for inundated soils. Cables should be spliced only in manholes and handholes. The splices must be waterproof and suitable for submersion.

8. Unit substations, switchgear, and motor-control centers should be equipped with heaters and screens as described above.

9. Motors and generators should be totally enclosed and equipped with heaters which are energized when the unit is not running, or a suitable low voltage should be applied to the unit when not running.

Mechanical Systems

Forced Ventilation

The use of mechanical fans to supplement the natural ventilation of a building is preferred to the use of air conditioning for reasons of cost and maintenance. Forced ventilation can accomplish two cooling sensations: replacing the warm interior air with cooler outside air, and providing evaporative cooling through air movement around occupants.

Air exchangers, typically in the form of attic fans, work most efficiently at night. They cool the building interior by pulling out the accumulated hot air, thus allowing cooler air to be drawn in. This nighttime cooling will generally create a cool building interior for most of the day also. In tropical buildings, however, this benefit is limited because the nighttime air temperatures remain high and offer little cooling potential. If properly located and detailed, the attic fan can always insure a good airflow up through the building interior, providing some cooling. Fan sizes and air movement rates can be calculated once the local climatic data are known.

Air-circulating fans are used for the sole purpose of increasing the evaporation from the occupant's skin. Circulating fans should not be operated when temperatures rise much above 98°F (37°C) because the resulting airflow can lead to a net heat gain instead of a desired heat loss by the body. Large ceiling fans have long been used, although they require high ceilings (from 9 to 10 ft or 2.7 to 3.0 m min.) for safety. Ceiling fans do provide a good vertical jet and also a horizontal flow close to the floor which is quite useful. They also have the lowest ratio of power consumption to air handling capacity, making them very cost efficient.[23] Their disadvantage is that they require higher ceilings, thus increasing wall areas significantly and causing more heat gains if the walls cannot be shaded effectively.

Air Conditioning

When air conditioning is to be incorporated into a building design in the tropics, every effort should be made to create an energy-efficient building. The high costs of energy and the large cooling load caused by the high temperatures and humidity emphasize the importance of a compact, well-insulated structure. The rooms should be no larger than necessary because the volume of air in a building dramatically influences the air conditioning load. The building shell should be well insulated, and glass areas and placements should be carefully considered to minimize the daily heat gains. Insulation types and thicknesses should be determined for each application.

Insulation needs to be protected from the penetration and condensation of water vapor just as it is in more temperate climates. Since the predominant heat flow is reversed in tropical construction from outside to inside, the vapor barrier should be applied to the external face of the insulation. However, moisture condensation can also occur on the inside face if the internal air becomes saturated. In these situations it is recommended to use closed-cell insulation (polystyrene and polyurethane) because they do not allow moisture penetration.

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[23] B. S. Saini, *Architecture in Tropical Australia* (Melbourne University Press, 1970), p 35.

To provide an adequate interior environment both the relative humidity and air temperature need to be kept within certain ranges. Commonly used air-conditioning systems (both central and local units) control the temperature directly and depend upon accurate sizing of the refrigeration unit to produce acceptable humidity levels. Dehumidification in these systems occurs because the air passes through a set of cooling coils, causing excess water vapor to condense. This process works adequately as long as the refrigeration unit is operating. If its operation is intermittent, however, the relative humidity can increase to high percentages because of internal moisture production (from sources such as people breathing and sweating, cooking, and cleaning). Hence, proper sizing of these conventional systems becomes very important and requires that the building loads be accurately determined and maintained.

It is often recommended that the system be undersized to allow almost continuous operation, insuring adequate dehumidification and satisfactory air circulation. If the building loads vary, it is recommended that the refrigeration unit should have a variable capacity. Such a system can be created by placing several small, individually controlled cooling coils in series instead of using only one larger coil. Where fine control of both the relative humidity and temperature is required, a central or terminal reheat system can be used. Such an air-conditioning system is for use in buildings housing sensitive items such as computers or communication equipment.

Independent room air-conditioning units offer the advantage of low initial costs along with simplicity of installation. This type of air conditioner is most practical for use in existing buildings. The use of room units should be avoided in new construction because they are less efficient (power consumption is 50 percent higher than for central units), they are noisy, and they provide poor circulation. In addition, the condensation water must be drained off, requiring special details; more typically, it is left to run down the facade. If window units are used, they should have a suitable corrosion-protection system.

A fan-coil unit is the other type of local air conditioning system in common use. Experience at naval facilities in the Far East has shown that these types of units present severe maintenance problems.[24] Placement of individual fans and cooling coils in each room subjected the equipment to a good deal of misuse and poor maintenance. Locally high humidity levels caused by doors and windows being left open, by wet clothing, or by other factors resulted in condensate water drainage problems in many of the units or in not being able to maintain low enough humidity levels. Therefore, fan-coil units are not recommended.

Criteria for mechanical air conditioning system design are given in Appendix D to offer guidance in the selection and protection of equipment.

Heating

In general, heating will be required in only a few locations and very infrequently. Portable electric resistance heaters are convenient and should provide sufficient capacity for occasional use, but they do pose safety hazards. Centralized heating systems are usually not required, but if needed they may consist of an electric resistance coil in the air handling unit or a heat pump.

Summary Recommendations

1. In lieu of air conditioning, forced ventilation created by attic or ceiling exhaust fans is recommended. Sizing is dependent on several factors and should be determined once local conditions are known.

2. Air-circulating fans are also effective at close range in providing a cooling sensation. Ceiling-mounted fans are most efficient but require higher ceilings.

3. Forced ventilation is not advised at ambient temperatures above 98°F (37°C).

4. The use of permeable insulation in air-conditioned buildings requires that a vapor barrier be placed on the external face of the insulation and possibly on the interior face, depending on internal humidity levels.

5. Central and room air conditioners should be undersized to insure almost continuous operation and adequate dehumidification.

6. Where fine control of both temperature and humidity is required a central or terminal reheat system should be added to the system.

7. Room air conditioners should be used sparingly because of their power inefficiency, high noise levels, and condensate water runoff problems.

[24] R. J. Moore and L. A. Spielvogel, *Trip to Naval Facilities in Guam and the Philippines* (trip report), October 1976.

8. Fan-coil units should not be used because of the severe maintenance problems they pose.

9. If heat is required, portable resistance units should supply enough capacity.

Plumbing

Corrosion Protection

Tropical conditions probably have the least effect on plumbing systems as compared to other aspects of building construction. The various materials used in plumbing for temperate zones are generally adaptable to tropical climates also. The major problem is corrosion because of the high humidity, the alkaline soil, and air conditions associated with the climate. The materials commonly used are affected in varying degrees. Recommendations concerning specific materials which have been used in Navy facilities are listed below.[25]

1. Cement-mortar-lined cast-iron pipe is recommended for buried water piping 4 in. (10 cm) and larger in diameter. Buried piping with a diameter of 3 1/2 in. (8.9 cm) or less should be copper tubing. Where copper tubing is to be buried under a slab in coral, adequate corrosion protection is required (a prime coat and two coats of coal tar are recommended).

2. Above-ground water supply lines and interior piping should also be made of copper tubing. In addition, exposed insulated piping should be provided with a stainless steel or aluminum jacket to minimize mold and physical damage.

3. Where ferrous metal piping is uninsulated in external or internal locations it should be galvanized and protected with an adequate coating system.

4. Plumbing fixtures should be made of heavily chrome-plated bronze, stainless steel, or (in some cases) glass. The use of enameled steel, cast-iron, or zinc-alloy fixtures is not recommended because of past corrosion problems.

Condensation Problems

Because of the high relative humidity, all cold water supply piping should be insulated to prevent "sweating." Condensation can also be a big problem for waste piping where plumbing fixtures have a high use rate. Insulation of the waste piping in such locations is recommended to prevent damage to finishes and to discourage mold and mildew. Since mold growth is a problem, all vapor barriers and coatings covering the pipe insulation should have mold-resistant properties.

Bedding

Plumbing lines must be protected from the movement of the expansive soils which typically compose the surface soil layer in tropical regions. This active layer expands and contracts with seasonal groundwater conditions, resulting in varying support conditions for the piping. Soft copper or galvanized steel pipe should be used where possible because of their good ductility. If more brittle material, such as cast iron, is used for piping, care must be taken to insure that the soil's expansion and contraction forces will not affect the plumbing lines. Protection can be provided by trenching through the active layer and then infilling with an inert sand or gravel base.

The large amount of wet weather also strongly influences the installation of water and sewer lines. Plumbers in wet-weather areas should carry portable pumps to pull excess water out of utility trenches before installing the plumbing. If may even be necessary to use temporary shelters over the trenches if the system is installed during the monsoon season.

Summary Recommendations

Whatever piping materials are used, adequate corrosion protection must be provided. Suggested protections for the specific materials mentioned above should be followed. All supply and certain waste piping should be insulated and protected with a mold-resistant covering. External plumbing lines should be buried in properly bedded trenches. Where soil movement is large, copper or galvanized steel piping should be used. Trenches should be protected during wet periods, and portable pumps should be used when needed to pull out excess ground- and rainwater during construction.

Paints and Coatings

General

Tropical climates create a number of weathering agents which deteriorate exposed building materials. Paint and coating systems are typically used to provide protection against these destructive elements. Intense sunlight, high temperatures, and high humidity levels all lead to the accelerated breakdown of paints. Also, in coastal locations the salt-laden air is particularly aggressive towards coating systems. Deterioration ranges from defects of appearance to complete film breakdown.

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[25] *Material and Design Criteria for Construction in Tropical Environments*, NAVFAC Draft Report (Department of the Navy, 1977), p 15401-1.

Fading or color change of the pigments; loss of gloss or finish; development of chalking; mold and algae growth; and cracking, blistering, flaking, and peeling of the paint film are all signs that paint decomposition has started and should be remedied.

The breakdown of paints can be delayed by using materials suited to the climate and the substrate, and by applying them correctly with an adequate number of coats on properly prepared surfaces. An excellent source of information on paints and coatings is the Department of Defense manual titled "Paints and Protective Coatings" (Army TM 5-618), which should be consulted for general guidance.

The effects of sunlight, heat, and moisture on the external paint film can be minimized by shading the walls using overhangs or vegetation. However, vegetation should not be planted in close proximity to the building face. An increased local relative humidity is created by the plant's respiration cycle and obstruction to light and wind. High humidity levels encourage mold growth and should be avoided. As mentioned in the earlier section on roofing, the use of a splash apron to handle roof runoff is important because the apron will reduce the amount of rainwater and dirt splashed up onto lower wall sections.

The selection and application of a particular coating system should be based upon the following factors:

1. The substrate material to be protected such as wood, concrete, steel, or existing paint

2. The condition of the substrate; e.g., rough, smooth, porous, or corroded

3. Surface preparation requirements such as sand blasting, chemical treatment, or hand brushing

4. The finish desired; e.g., glossy, flat, or semiglossy

5. The method of application; e.g., brush, roller, or air spray

6. The environment in which the coating system will be applied and maintained.[26]

[26] *Material and Design Criteria for Construction in Tropical Environments*, NAVFAC Draft Report (Department of the Navy, 1977), pp 09910-1, 2.

Fungicides

In hot, humid climates the main requirement of a paint film is to resist mold growth and to prevent water penetration. Water impermeability is a common characteristic of almost all paints, but mildew resistance is not normally incorporated into the paint composition. All paints, primers, and enamels used in tropical locations should contain a fungicide to inhibit mold growth. The addition of the mildewcide by the user is not advisable because of the toxity of the chemicals used. Also, there is a possibility that the chemical will be incompatible with the paint unless properly matched. The fungicidal agent should be introduced at the factory and should be of a type that will not adversely affect the color, texture, drying, or durability of the coating. The most effective fungicides have proven to be those containing mercury, but mercurial fungicides have been banned for use in the U.S. in the interest of public health. A list of fungicides specified for construction in the Panama Canal Zone is given in Table 3, but it should be noted that new and possibly more effective fungicides are currently entering the market and should be reviewed.

Other methods to reduce mold growth are to:

1. Specify glossy finishes whenever possible because the harder and smoother the film is, the more it resists mold attack.

2. Do not add any oil or thinners containing oil to the paint, as these may provide a food source for molds.

3. Insulate the walls of air-conditioned spaces very well, as they are prone to become damp from condensation of the warm, outside air. Intermittent air conditioning may create moisture problems on the inside walls when moist warm air is admitted.

If fungus, mold, or algae has developed on building surfaces, a shown in Figure 40, and treatment or repainting is planned, the bacteria must be killed and the paint film disinfected to prevent unknowing workers from infecting their lungs, ears, and eyes. Some common fungicidal washes are listed in Table 4. They should be used with caution and kept away from contact with the skin and eyes because these compounds are toxic to varying degrees.

Interior Coating System

In general, internal painting requires no special provisions beyond the addition of a mildewcide. The

Table 3
Recommended Fungicides*

A. For solvent-based paints, the funcidide should be one of the following:

1. One percent
   a. Cuprous oxide
   b. 8-quinolinolate
2. Four percent tetrachlorophenol, based on the weight of the nonvolatile contents of the paint.
3. Approved equal.

B. For water-dispersable coatings, the fungicidal agent should be one of the following:

1. Two percent pentachlorophenal with two percent sodium pentachlorophenate.
2. Approved equal.

*(From *Specifications for Construction of 48 U.S. Quarters at Various Locations in the Canal Zone*, Serial No. pc-74-45 [Panama Canal Company, April 1974], p 15-2.)

problems of exposure to sunlight and rain are not encountered, but the weather will slow the drying considerably. Therefore, the products listed for interior use in Appendix D of the Paints and Protective Coatings Manual (TM 5-618) are applicable and are recommended. In particular, TT-P-29 has been suggested for general interior use, especially for interior concrete and masonry.[27] The guidelines for paint storage, surface repair and preparation, and paint application given in TM 5-618 should be carefully followed.

Exterior Coating Systems

Wet weather not only slows down or stops the application of exterior paint, but it also affects the quality of the paint job. Exterior painting should not be attempted in rainy weather unless protection for the surface is provided during the painting and drying periods.

Another moisture problem arises from the high humidity of the region. Where the relative humidity is over 85 percent, exterior latex paint should be used with caution, as problems have arisen in these conditions.[28] Also, manufacturers of stain have stated that high moisture content in wood will inhibit adequate penetration of the stain. In marine atmospheres the salt-laden air will often cover all exposed construction

[27] *Material and Design Criteria for Construction in Tropical Environments*, NAVFAC Draft Report (Department of the Navy, 1977), p 09910-2.

[28] *All-Weather Home Building Manual* (NAHB Research Foundation, Inc., November 1975), p 129.

Table 4
Fungicidal Washes*

For treatment of algae and lichens on external walls and roofs use:

1. Copper sulfate, 1 oz in 1 gallon of water (8 ml per liter of water)
2. Copper carbonate, 1 oz plus 10 oz strong ammonia, in 1 gallon of water (8 ml of copper carbonate plus 78 ml ammonia per liter of water)

   (The second is preferred; both may cause slight stains on some materials.)
3. Bleaching powder, 8 oz in 1 gallon of water (63 ml per liter)
4. Household bleaching solution, diluted as recommended. (3) and (4) may also be used for molds on paintwork but may cause bleaching or other side-effects.

For treatment of molds on paintwork and timbers:

5. Formaldehyde (formalin), 5 percent solution (4 pints of 40 percent formalin in 10 gallons of water or 1 liter in 20 liters of water). May be found unpleasant to use on interior surfaces.
6. Lysol, diluted normally (must be thoroughly rinsed off)
7. Sodium pentachlorophenate ('Santobrite'), 2 lbs in 10 gallons of water or 960 g in 40 liters of water
8. Sodium salt of salicylanilide ('Shirlan NA'), 2 lbs in 10 gallons of water or 960 g in 40 liters of water
9. Proprietary washes containing various fungicides dissolved in water or in solvents such as white spirit or methylated spirits, used as directed.

*(From P. Whiteley, *Recommendations for Painting in Tropical Climates*, Tropical Building Studies No. 4 [Building Research Station, Garston, England, 1962], p 19. Reproduced by courtesy of the Director, Building Research Establishment, British Crown Copyright Controller, Her Majesty's Stationery Office.)

with microscopic crystals of salt.[29] Since these crystals have a high affinity for moisture, a surface may appear dry even when it is covered with a film of moisture. This moisture accumulates on all exposed surfaces but is especially hard to detect on concrete and masonry. If such surfaces must be painted, they should be primed with a coating which can be applied to damp surfaces (TT-P-19 is recommended).

Most exterior coating systems are designed for application to specific substrates and for specific exposure conditions. Various building materials will require different coating systems because no single coating system can provide acceptable performance on all types of materials in the tropical climate.

[29] *Material and Design Criteria for Construction in Tropical Environments*, NAVFAC Draft Report (Department of the Navy, 1977), pp 00910-3 and 4.

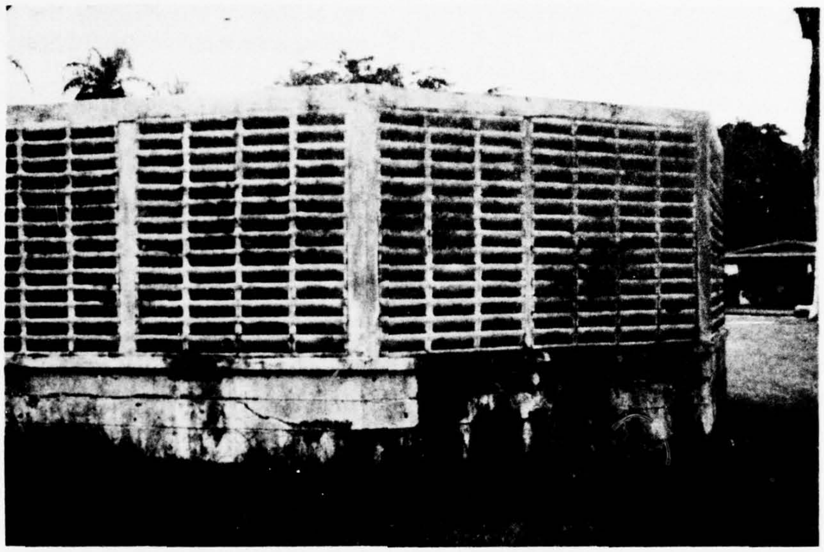

Figure 40. Mold growth.

The guidelines for exterior painting given in TM 5-618 should be followed to insure the best performance of a particular paint system. A list of exterior coatings recommended by NAVFAC based on its experience is included in Appendix E, Table E1. Note that cement fills and washes (TT-P-21 and TT-P-35) should be used on new masonry and concrete whenever possible based on experience in the Far East.[30]

All exterior surfaces should have a protective cover of at least three coats of paint, including primer, except for concrete and masonry, for which two coats are acceptable. All exterior coatings must contain a suitable fungicide, as discussed previously in this chapter.

Summary Recommendations

1. Use overhangs and vegetation to shade wall surfaces as much as possible.

2. Review the available coating systems and select one based on the substrate material, its condition, the method of surface preparation employed, the finish desired, the method of application, and the environment in which the coating must work.

3. Incorporate appropriate fungicides in all paints to be used indoors or out. Additional protection may be gained by specifying glossy finishes, preventing the addition of any thinner or oils to the paint, and insulating the walls of air-conditioned rooms well.

4. Where bacterial growth has started, the paint film should be disinfected before any surface treatment or repainting is started. See Table 4 for recommended treatments.

5. Any of the products listed in Appendix D of TM 5-618 may be used for interior painting. TT-P-29 is recommended for general interior use.

6. Exterior paints must be carefully matched to the substrate. A set of reliable paints for the various building materials is listed in Appendix E, Table E1.

7. Cement fillers and washes should be used in preference to paint for new concrete and masonry.

8. All exterior surfaces require a minimum of three coats of paint, except that concrete and masonry can be satisfactorily covered in two coats.

[30] ARMM Consultants, Inc., *Moisture Problems in Buildings*, Contract N 6 2467-76-C-0696 (Department of the Navy, 1976).

4 DESIGN AND CONSTRUCTION GUIDELINES FOR DESERT FACILITIES

Planning and Siting

General

The location of a facility within a site should be determined by analyzing the constraints and features of the site. These factors include the climatic constraints of temperature, precipitation, and prevailing winds as well as the natural features of the groundplane such as the topography, ground cover, drainage patterns and soil types. Other important site considerations are possible access points to existing roads and utilities.

Climatic Constraints

Design constraints in a desert environment are very severe because of the climatic extremes to which buildings are exposed. Desert environments are severly controlled by the effects of the weather. The elements of weather are essentially temperature, precipitation, and wind. How each of these elements affects desert life will be discussed below.

Temperature. Solar radiation beats down on desert regions with great intensity and is seldom diffused by clouds. Summer air temperatures range up to 55°C (131°F) in the daytime, with night temperatures dropping to 25°C (77°F). Winter air temperatures are more moderate, ranging from 35°C (85°F) in the daytime and to 0°C (32°F) at night.

Ground temperatures are typically much hotter than the air temperatures given above but vary dramatically depending on the ground surface. Natural relief from the extreme daytime temperatures is achieved by shading the groundplane, which can cause temperature drops of up to 10°C (18°F).

Siting of desert facilities to minimize exposure to direct sunlight can be accomplished by careful design at both the site and building scale. Several solar orientation guidelines for the design of the site and of individual buildings in desert environments are as follows:

1. Buildings should be grouped into oblong blocks which are oriented in an east-west direction to minimize wall exposure to the low sun angles of the morning and afternoon, as explained in Chapter 3.

2. Streets should be narrow and building setbacks should be minimal. With the right proportions, the buildings can shade a good portion of the walks and streets for most of the day, as shown in Figure 41.

3. Only the major streets should be paved to prevent the buildup of smooth, reflective surfaces. Walks and parking areas should consist of light, coarse materials.

4. Parking areas should be at least partially shaded to prevent excessive buildup of heat in these areas. Shade can be provided by several means, as shown in Figure 42.

5. Walkways and open spaces should be kept small and shaded, where possible, by vegetation.

6. Buildings in general should be multistory (2 or 3 stories) to decrease roof areas, which are exposed to much more radiation than the walls. For example, Figure 43 shows two buildings identical in floor area but of a different shape. Building A has only half the roof area of building B and yet only one-third more wall area.

7. Building form should utilize large overhangs or arcades to shade walls and openings. Figure 44 shows how a large overhang protects the building walls from the sun.

Desert Winds. Wind in desert areas is practically unceasing and is a major climatic force which must be planned for in these regions. The constant high winds are believed to be created by convection currents set up during the day by the sun's heat. Because the wind moves great amounts of hot, dry air it has severe dehydrating effects on the desert environment. In addition, the wind always carries fine soil particles which abrade building elements, clog mechanical devices, and accumulate on every surface.

Because of its destructive potential, the wind must be lifted, deflected, and guided. Yet, where possible, it must be used to every advantage for ventilation. By following the guidelines offered below, adequate wind protection may be achieved for most locations.

1. It is recommended that, where feasible, a permanent barrier should be constructed around the perimeter of the installation to lift and carry the wind over it (Figure 45).[31]

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[31] K. Kelly and R. T. Schnadelbach, *Landscaping the Saudi Arabian Desert* (Delancey Press, 1976), p 30.

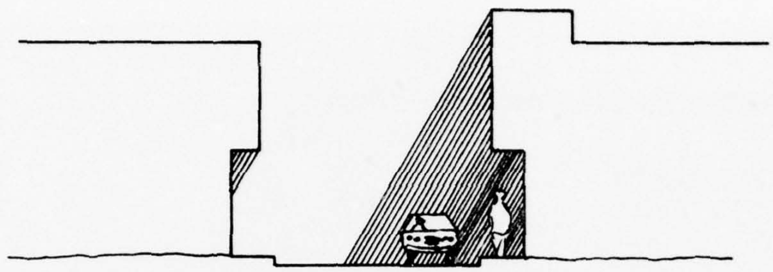

Figure 41. Building setback.

a. Independent Shade

b. Building Overhang

Figure 42. Parking shades.

a. Two-Story Building

b. One-Story Building

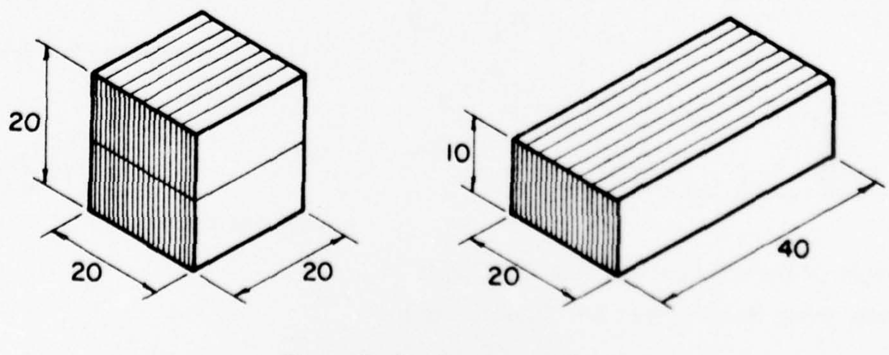

Figure 43. Roof area comparison.

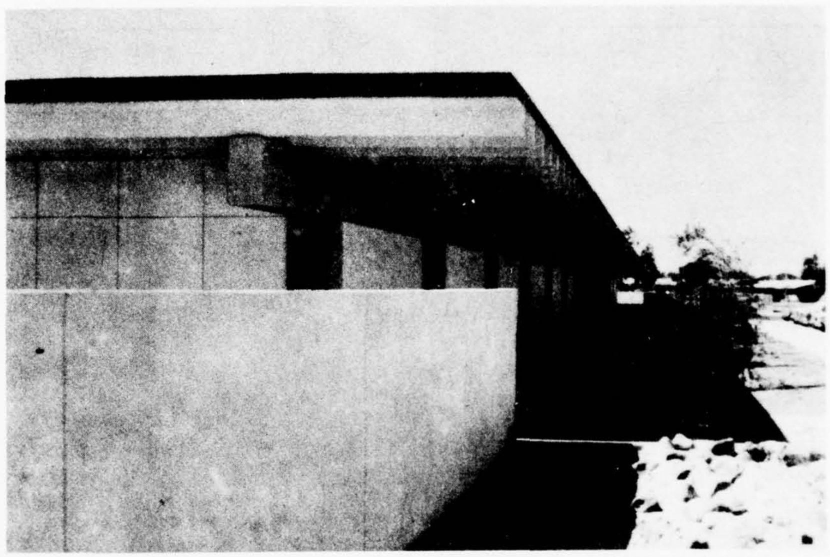

Figure 44. Protective overhang.

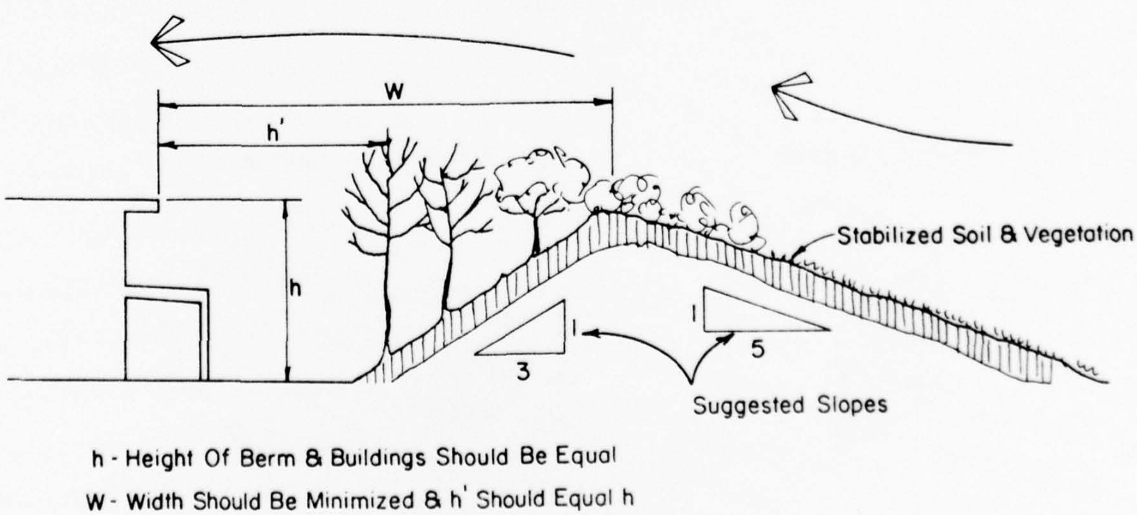

Figure 45. Wind barrier.

2. The street and open space patterns should be aligned perpendicular to the prevailing winds. Because these spaces are potential weaknesses in wind protection, they should be limited in size and number as much as possible, as shown in Figure 46.

3. Large open spaces should be avoided, but where necessary they should be bordered by trees and a soil berm similar to the larger community barrier berm as shown in Figure 47. This arrangement is necessary to keep the wind from dropping into these depressions and affecting the surrounding buildings.

4. Building forms should be of a fairly constant height ranging from one to three stories. High rises should not be constructed because they create a good deal of turbulence and eddies, as pictured in Figure 48.

5. Individual buildings need to become internalized to provide wind protection for their exterior spaces. Both exterior and interior space can use wind chimneys or towers to provide ventilation (see Figure 49). More specific methods of inducing natural ventilation for individual buildings will be analyzed in the section on exterior walls and wall openings. In general, ventilation is discouraged during the daylight hours to prevent heat infiltration and is recommended at night to provide dissipation of the heat built up during the day.

Precipitation and Humidity. Because of the small amounts of precipitation received annually in desert areas, fresh water resources available to the site need to be conserved. The sun's effect on plant life alone has placed severe limitations on the hability of most desert regions. In addition to the lack of surface water, humidity levels are extremely low because of the sun's intense heat. Dehydration is a critical problem, and every effort should be made to retain precipitation and to recycle potable processed water to minimize wastes.

The scarcity of water resources leads to several design recommendations:

1. Storm drainage systems should be avoided. Instead, natural drainage patterns should be established. The periodic runoff could be stored in wells and cisterns and later used for the irrigation of local plants. See Figure 50.

2. Use landscaping materials which have minimum water needs. The quantity of plants and their needs for water should be calculated and water resources determined before planted areas are planned.[32] Figure 51 shows landscaping adapted to the climate.

3. Keep open spaces small to reduce evaporation losses from planted areas.

4. Do not create any unnecessary surface water courses, pools, or fountains because evaporation losses from these water bodies can be as high as 20 percent daily.[32]

Natural Constraints

Topography. Desert areas, when subjected to the periodic rainfall of the winter season, often experience flash floods because of the relative impermeability of the groundplane. Natural drainage swales exist in all desert environments and must be considered in the early stages of site planning. To prevent flood damage, buildings should be kept away from the floodplains of drainage swales.

Vegetation. Plant life provides a method of controlling the shifting nature of desert areas. Its importance as a soil stabilizer and sun screen has already been mentioned. The extremes of the desert soil, wind, water supply, and sun create a very specialized family of plants which are best adapted to the desert environment. When landscaping in desert locations, the use of indigenous plants is strongly recommended to insure suitability and prevent waste. Desert plant types can be found in sources listed in the bibliography (Kelly and Fry).

Water Supply. Water is the missing element which defines a desert. An adequate water supply is critical to the operation of any desert installation. Access to a nearby water source, typically an underground aquifer, is vital to making a site feasible for development.

Soils. Soils in desert locations vary widely from place to place, ranging from vast areas of sand, exposed bedrock, boulders, pebbles, and natural cement. Soils are extensively underlain by a layer of gravel which has been cemented together by the soil salts and adjacent lime. Hardpan, as this natural cement layer is called, presents drainage problems. However, it usually does have a good bearing capacity which should be adequate for most building foundations. Since vegetation is an important site consideration, any arable land on a site should be fully utilized for landscaping purposes.

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[32] K. Kelly and R. T. Schnadelbach, *Landscaping the Saudi Arabian Desert* (Delancey Press, 1976), p 49.

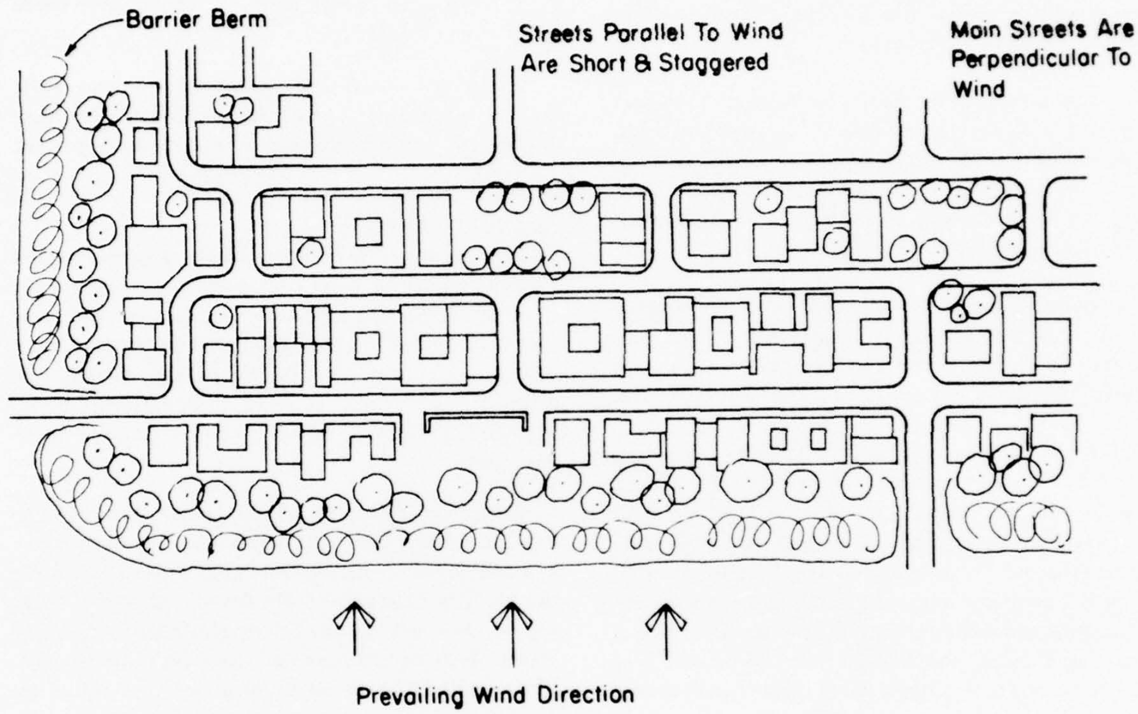

Figure 46. Street pattern.

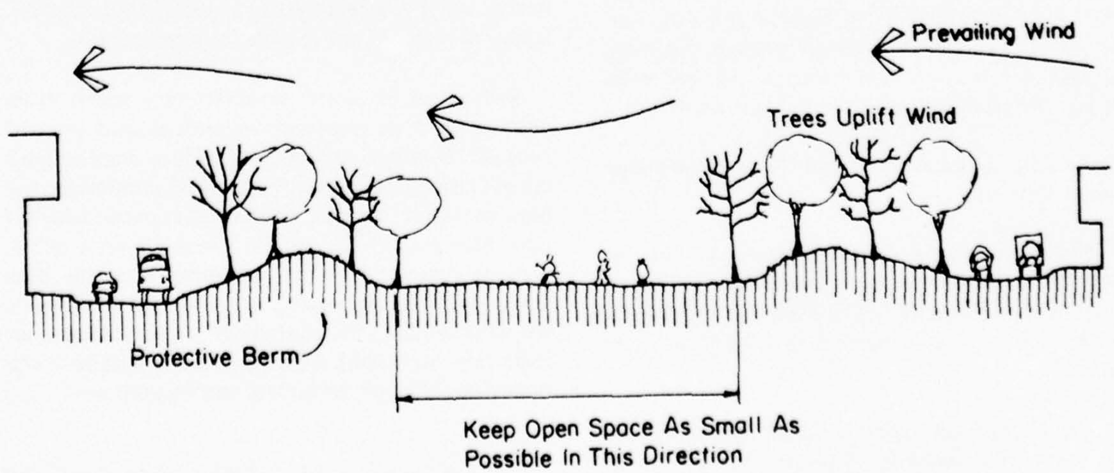

Figure 47. Open space protection.

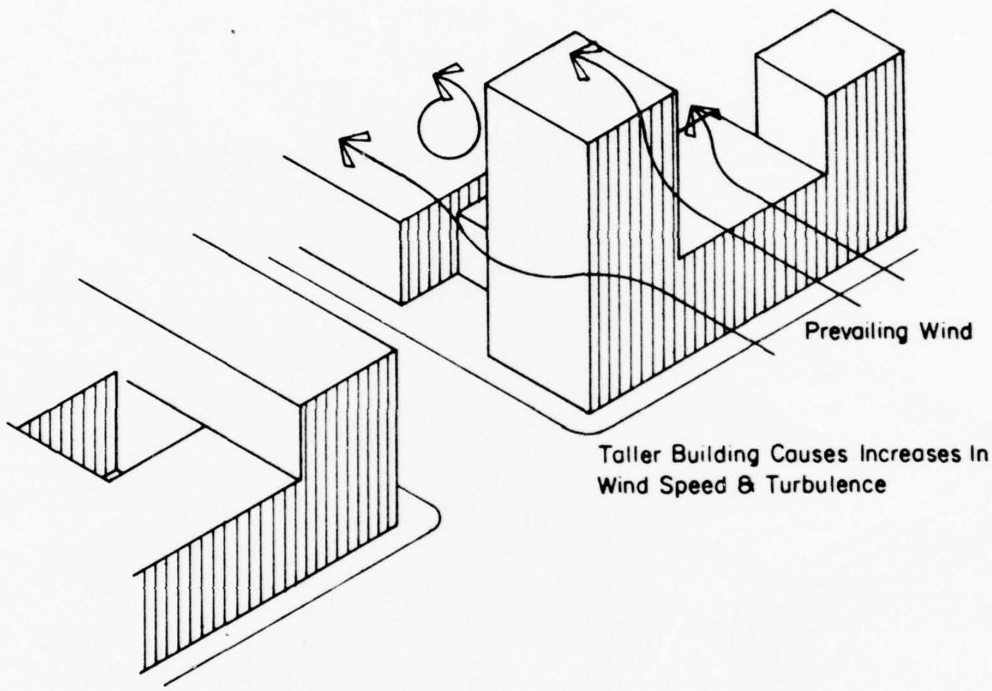

Figure 48. Effect of wind on high rises.

Summary Recommendations

1. Group buildings into oblong blocks oriented in an east-west direction.

2. Keep streets as narrow as possible and minimize building setbacks to provide shade for the walks and streets.

3. Use paving only where required to reduce the amount of reflection.

4. Shade parking areas to prevent excessive heat buildup.

5. Keep walkways and open spaces shaded; use smaller, protected courts for open space.

6. Use multistory buildings (two to three stories) to decrease roof areas.

7. Use large overhangs or arcades to shade walls and openings.

8. Use a soil barrier berm at the perimeter of the installation to lift wind over the site.

9. Align street and open-space patterns perpendicular to prevailing winds.

10. Protect open spaces with trees and a soil berm similar to the larger community berm.

11. Maintain a constant building height, and do not extend buildings above it to prevent increased wind effects.

12. Internalize individual buildings to provide both wind and solar protection.

13. Trap runoff and store it in underground cisterns placed beneath drainage swales.

14. Use landscaping materials which have minimal water needs.

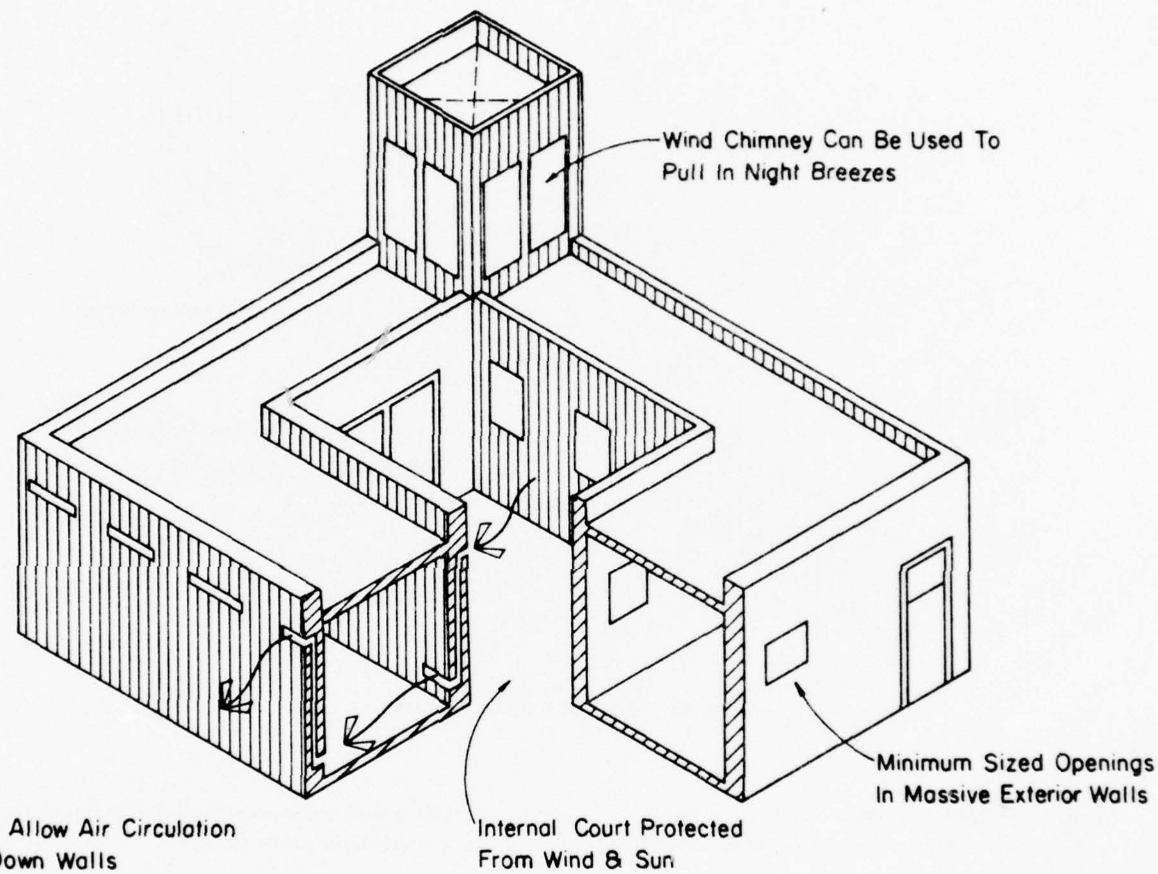

Figure 49. Internal courtyard.

15. Keep open spaces small to reduce evaporation losses from planted areas.

16. Avoid creating areas of exposed surface water because of high evaporation losses.

17. Keep buildings away from the floodplains of large drainage swales.

18. Use indigenous plants since they are best adapted to the local desert environment.

19. Insure that a major water supply point is easily accessible.

20. Use recycling water systems to minimize wastes.

21. Take and test soil samples to insure proper foundation design despite widely varying soil types.

Foundations

General

Soils. As previously described, soil conditions in desert regions vary widely. There are vast areas of sand, exposed bedrock, gravel, and natural cementious materials. Fertile soil is found in isolated pockets along the natural drainage swales of these areas. This variation in soil conditions is further compounded by the erosive effects of constant desert winds and periodic

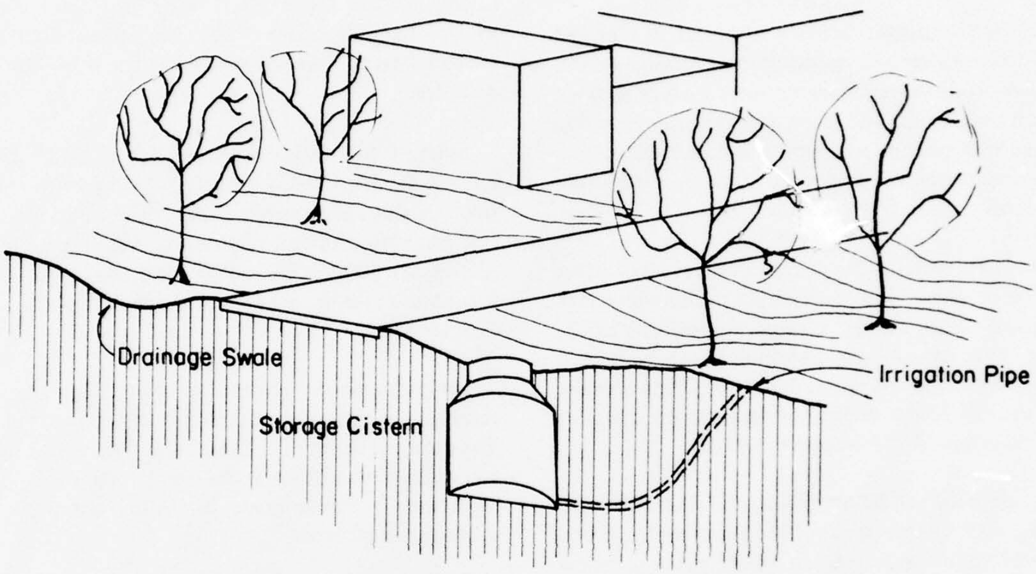

Figure 50. Storm drain cisterns.

Figure 51. Desert landscaping.

flash floods. Soil types cannot be determined simply on the basis of geological conditions as is done in other geographical areas. Instead, soil conditions at the actual site must be determined.

Termite Protection. Building materials in arid and semiarid regions are also susceptible to termite attack. Several types of subterranean termites are well adapted to desert conditions, and steps should be taken to protect against them. See the termite section discussion in Chapter 3 and consult Appendix A for chemical application rates.

Erosion Protection. Erosion in certain desert areas can often be severe due to the occasionally high winds and periodic flash floods. Erosion and drifting of the surface layers of soils around buildings can be limited by wind protection and soil stabilization. Wind erosion, which usually occurs at the building corners, must be limited to insure overall building stability.

Two methods can be applied to the foundation design to prevent wind erosion from causing structural damage. The first is to extend the foundation below the maximum depth of erodible soil, as shown in Figure 52. The depth of potential erosion is often difficult to determine for individual sites without obtaining information on local conditions. Cited examples show that erosion of up to 24 in. (61 cm) is not uncommon.[33]

The second method is to stabilize the soil along the perimeter of the foundation to minimize erosion by the use of plant root systems, gravel backfill, or chemically treated soils in problem areas such as building corners. These techniques are illustrated in Figure 53.

Water erosion around foundations must be prevented also. Direct erosion of foundation soil can occur during periodic rainstorms and flash floods. To avoid such problems, roof runoff must be carried away from the building perimeter, and positive drainage must be established around the building. Soil subsidence or expansion under the foundation, which also occurs because of water in foundation areas, is another problem which can be eliminated if moisture is not allowed to accumulate.

Systems and Materials

Because of the wide soil variability typically encountered in desert areas, a variety of different foundation types are applicable. In general, shallow systems are acceptable for all types of buildings. Raised foundations, whether of the point or perimeter type, should be avoided because they expose the floor system to the intense heat of the desert. The foundations and much of the building itself should be depressed into the groundplane to take advantage of the earth's insulative qualities.

Suitable foundation materials for arid climates are limited. Wood, which is normally used in raised foundations, is not recommended. Reinforced masonry, precast concrete, and cast-in-place concrete are preferred. All remain durable in desert conditions provided that adequate cover is used around the reinforcing (see Chapter 5).

On-grade concrete slabs supported by perimeter footings are generally suitable for desert construction. The required depth of the footing is determined by soil and erosion conditions at the site. Depending on depth requirements, either grade beams or continuous wall footings can be used.

When using slab-on-grade foundations special consideration should be given to preventing significant buildups of moisture around the building because the higher local moisture content may cause either soil collapse or expansion, depending on type of soil, ultimately resulting in structural failure. Runoff drainage should be kept away from the foundation.

Generally, there are few foundation problems in desert areas of the southwestern United States except where caliche or adobe soils are found. When working in caliche soil, which swells and shrinks with changes in moisture content, the soil must be removed and filled with sand. The sand is then wetted and compacted before pouring the foundation. The caliche soil can be removed easily since it normally runs between 12 and 24 in. (30 to 60 cm) in depth. Adobe clay runs considerably deeper than caliche. The removal of adobe clay is, therefore, not normally attempted. Instead, a thicker reinforced slab 8 to 9 in. (20 to 23 cm) thick is used to stabilize the expansion and contraction caused by the adobe clay.

In sandy clay and other desert soils, the soil under the foundation area must be thoroughly saturated with water and then rolled until the right degree of compaction is achieved. Figure 54 shows dimensions for a typical slab-on-grade foundation used for most single-family and townhouse foundations in the southwestern United States.

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[33] S. M. Johnson and T. C. Kavanagh, *The Design of Foundations for Buildings* (McGraw-Hill, 1968), p 60.

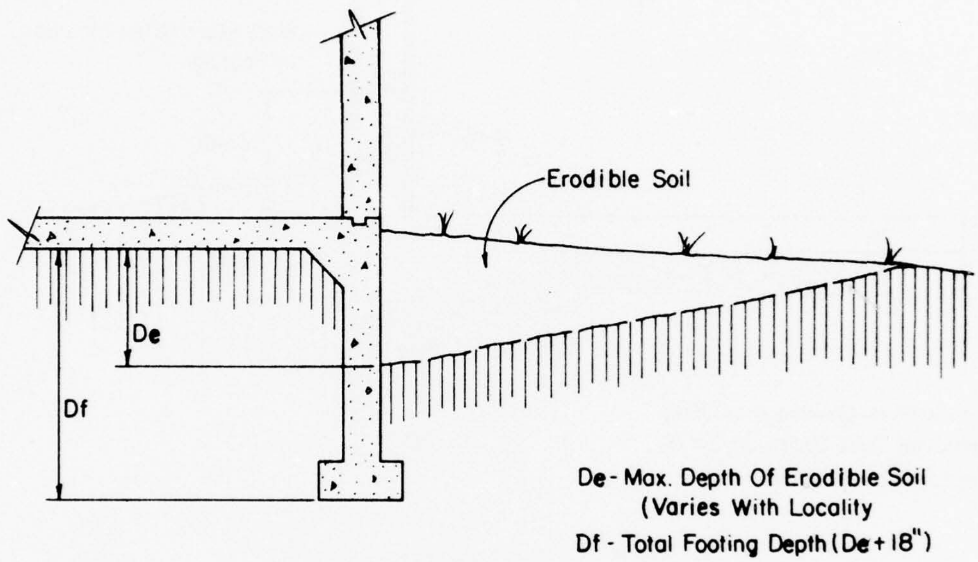


Figure 52. Suggested foundation depth.

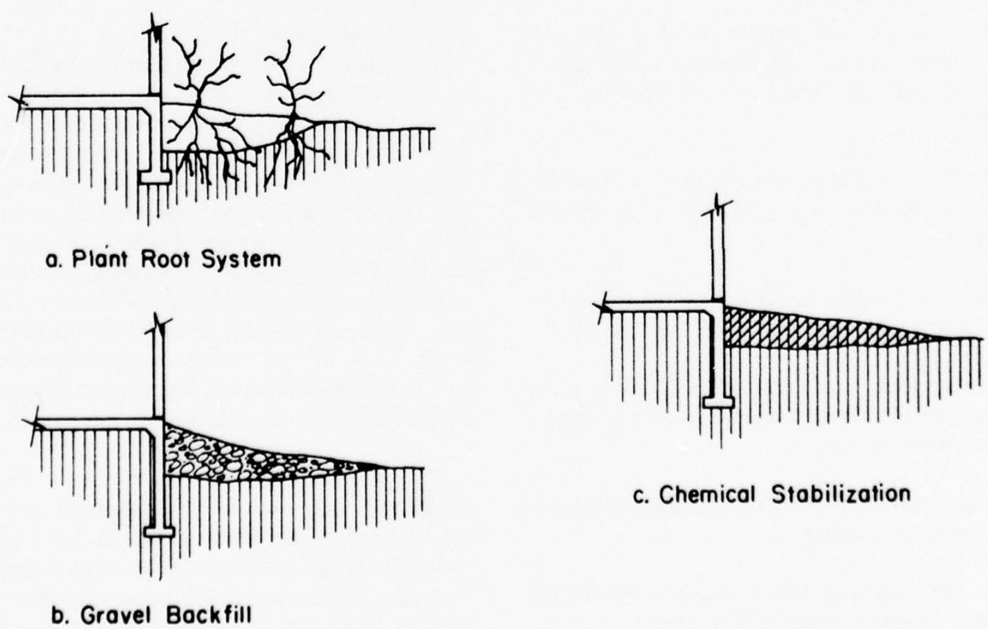


Figure 53. Soil stabilization.

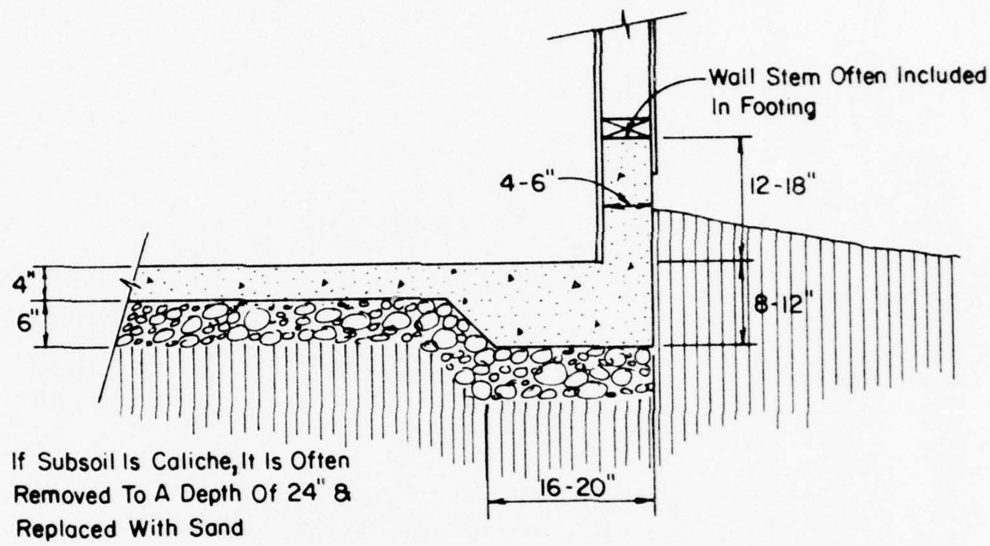


Figure 54. Typical slab footing.

Summary Recommendations

1. Investigate site soil profiles and determine mechanical properties from a soil analysis if possible, or if not, make assumptions based on inspection of local building types.

2. Once the soil type is determined, check possible foundation restrictions before the system is selected and designed.

3. If local infestation conditions warrant, incorporate termite protection into the foundation design.

4. Provide wind protection or soil stabilization where required to prevent erosion around the corners of the foundation system.

5. Prevent water erosion by providing positive drainage away from the building.

6. Use the recommended foundation system for desert areas—on-grade concrete slabs supported by perimeter footings—whenever possible.

Floors

Desert Considerations

First Floor. By locating the first floor of the building on or below grade level in arid regions, the floor will be cooled naturally by the ground beneath it. Generally, this cooling is a welcome relief from the oppressive heat of such a region. In certain areas, however, the annual temperature fluctuates considerably, and the cool floors become very uncomfortable in the cold season. This problem can be remedied by using carpeting in the cool months, but in severe locations the use of a different floor system or of under-slab insulation is necessary. A quick study of the annual local temperature range should help in deciding whether to use a thermally conductive or resistive flooring system.

Upper Floors. Realizing that a two- or three-story building is much more thermally efficient in desert locations is important. If a multistory building form is to be used to its full advantage, it should be designed with the upper floor(s) cantilevered over the lower walls to provide maximum sun protection. By designing the upper story(s) so that it can be opened at night and

kept closed during the day, an even more efficient building is created. The floors of the upper story(s) should be well insulated to minimize heat transfer down through the building.

Construction Practices

Insulation. When slab-on-grade floor systems are used in arid regions, care should be taken to insulate the slab's perimeter. This insulation minimizes heat transfer through the slab to the building interior. The sketches in Figure 55 show insulation placement for different floor/foundation systems.

As mentioned previously, in some locations insulation will be required under the whole slab. The thickness and type of insulation used are determined by site design conditions.

Expansion Joints. The upper floor system(s) is similar to the roof and wall systems in that it will be exposed to significant temperature variations if the building is designed as suggested above. These temperature changes will result in differential expansion and contraction forces acting on the floor system. Monolithic construction, such as poured-in-place concrete slabs, is often damaged by these forces and should be avoided. The use of a floor system with a large number of small panels is recommended to reduce temperature stress and strain values.

Termite Protection. As discussed in the section on desert foundations, termites are present in some desert areas. Protection methods should therefore be applied to all permanent buildings constructed in termite-infested areas. Slab-on-grade floors are particularly susceptible to infestation because of the direct soil contact. Whenever possible, the soil beneath the slab should be poisoned (see Appendix A). In addition, all scrap lumber, concrete forms, and other organic matter must be cleared away from each building.

Other flooring systems also require protection, the nature of which will depend on the type of construction and the materials used.

Material Usage

General. In fully air-conditioned buildings (temperature and humidity controlled) any of the common flooring materials can be used. In naturally ventilated buildings, the materials choices are limited because of dust accumulation, extremely low humidity levels, and the effects of intense sunlight. Paved floors are recommended, as they best adapt to the restrictions of arid regions.

Concrete. Concrete is well suited as a flooring material because it is easy to maintain, is not greatly affected by the low humidity, transfers heat very slowly, and reradiates it very well. It is important, however, that the water, cement, or aggregate used for mixing must be free of impurities. The impurities will cause rapid corrosion of the reinforcing steel and consequent deterioration of the concrete. Adequate cover must be provided around all reinforcing steel. See Chapter 5 for more detailed information on the required materials and proper construction practices.

Floor Coverings. Where a finish other than concrete is required, the best materials have proven to be ceramic, stoneware, and terrazzo tiles.[34] Asphalt and vinyl-asbestos tiles are probably also acceptable but no substantiated evidence is available. Wood is not an acceptable material because the low humidity causes it to shrink, crack, and warp severely. Carpeting is an acceptable covering, but its use should be limited because of high maintenance costs. Carpeting is the only covering with good insulating qualities, and its use for insulating purposes is acceptable.

Summary Recommendations

Permanent Buildings. The floors should be either cast-in-place concrete slabs or precast panels. A floor covering, if required, should be selected from those mentioned above, and the construction practices listed should be followed.

Temporary Buildings. The floors should be concrete slabs on grade where possible. Although timber floors may hold up if adequate termite protection is provided, they should generally be avoided.

Exterior Walls

Design Considerations

Wall Types. Protection from the intense heat of the sun is a primary determinant in selecting a wall system for desert buildings. Traditionally, exterior walls have been constructed of massive earthern materials. These materials by their nature and thickness absorb the heat and reradiate it slowly so that little heat is gained during the day.

To prevent this type of wall from heating up over time, the heat gained during the day must be lost at night. The exterior surface of the walls will radiate heat to the night sky; in some cases this process may cool

[34]G. Lippsmeier, *Building in the Tropics* (Verlag Georg D. W. Callwey, 1969), p 178.

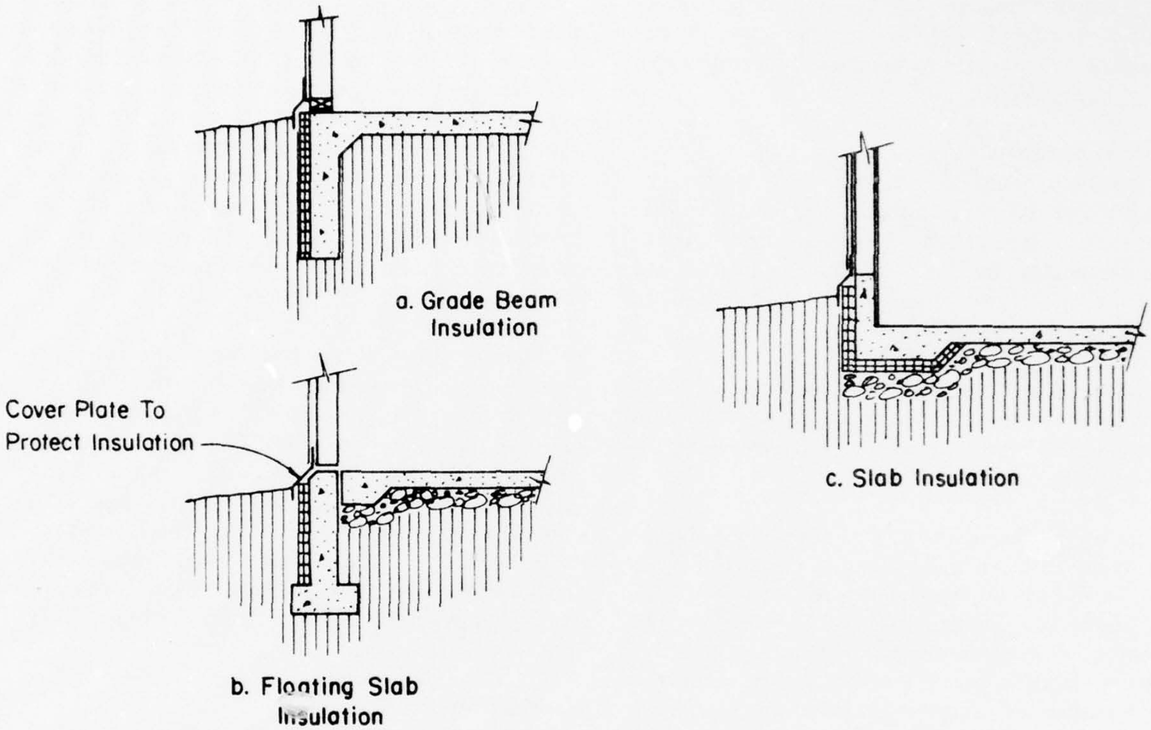


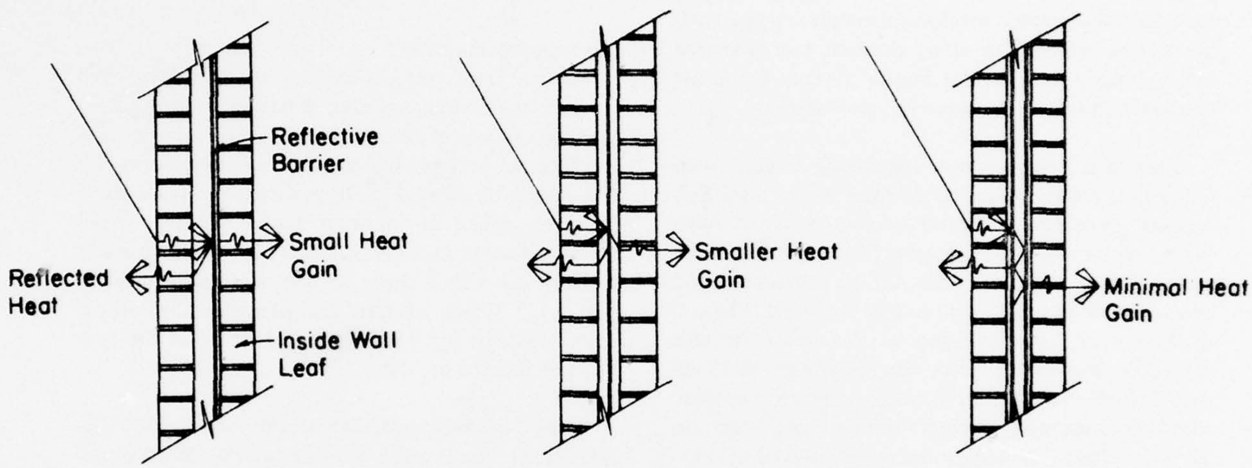
Figure 55. Insulation placement.

the walls sufficiently. Tests show that a brick wall 32-in. (80 cm) thick would prevent heat from ever penetrating into the interior.[35] Unfortunately, such a wall is far too heavy for most building types. Walls with thicknesses from 10 to 16 in. (25 to 40 cm) are often used. Because internal heat gains from these walls could become a problem at night, some ventilation is required to remove heat from the building interior. Solid wall thicknesses for different building types can be determined on the basis of the structure's use. The occupancy patterns of a building can be used to calculate how large the wall's heat lag should be to provide a comfortable interior while the building is being used. For example, an office building may need a wall that provides a 4- to 6-hour time lag, whereas a residence may require a 9-to 12-hour time period to delay heat entry into the building. Once the time lag and material have been decided upon, the optimum thickness can be calculated and incorporated into the building design.

An alternative to using massive walls for the whole building is to enclose only daytime living spaces with these protective walls and to make the walls enclosing nighttime spaces from lightweight materials. The heavy walls will remain cool during the day and lose the heat they gained during the course of the night. The lightweight walls will, on the other hand, be very hot during the day and cool off quickly once the sun goes down. This type of construction is limited primarily to residences since such buildings have separate use cycles occurring during day and night. The only disadvantages are that there may be some duplication of spaces and construction costs will be higher.

Double-walled construction is another suitable system for desert locations and offers several advantages over solid walls. The wall is made up of an outer leaf, a cavity, and an inner leaf, as shown in Figure 56. The outer leaf material should have low absorption, heat storage and conductivity characteristics. Lightweight, hollow bricks seem to be the best material for the outside leaf. The effectiveness of this type of wall can be increased by using a reflective barrier in the cavity space placed on the outside face of the inside leaf (Figure 56a).

[35] M. Danby, "The Design of Buildings in Hot-Dry Climates and the Internal Environment," *Build International*, Vol 6, No. 1 (1973), p 61.



a. Single reflective barrier on inside leaf.

b. Barrier suspended in air space.

c. Reflective barriers on both leaves.

Figure 56. Double-wall construction.

If possible, the reflective barrier should be suspended in the cavity (Figure 56b) to eliminate conduction heat gains through the barrier. The cavity space can be vented to cool the wall more efficiently. Some experts recommend using reflective barriers on each side of the cavity (Figure 56c) to trap the heat in the air space.[36] The trapped heat is then vented out.

Lightweight wall systems are not often used in desert areas because without adequate insulation they quickly absorb and transmit an intolerable amount of heat. When properly insulated, however, lightweight walls should be acceptable. Pre-engineered and panelized wall systems with adequate insulation offer promise, as they reduce construction time to a minimum. Care must be taken to prevent any path of heat gain through wall sections, such as windows, door frames, and panel connections, because gains through these elements can become sizeable. One advantage to using lightweight construction is that it would provide little heat storage capacity and the building would therefore cool off quickly at night.

Wall Openings. Unless wall openings are heavily shuttered during the day, they transmit large amounts of heat into the building interior. Glazing should be avoided where possible because of its high heat transmission quality. If glass is required it is recommended that sealed double glazing be specified.[37]

Natural ventilation of interior spaces during daylight hours is not recommended for residential buildings in arid regions. Tests have shown that, if ventilated throughout the day, a room's air temperature matched the outside temperature and remained high even after the outside temperature had dropped.[38] The same

[36] G. Lippsmeier, *Building in the Tropics* (Verlag Georg D. W. Callwey, 1969), p 162.

[37] Lippsmeier, p 179.

[38] M. Danby, "The Design of Buildings in Hot-Dry Climates and the Internal Environment," *Build International*, Vol 6, No. 1 (1973), p 65.

room not ventilated during the day had indoor temperatures 18 to 20°F (10 to 11°C) lower than the outside air temperature.

It is not always possible to use nighttime ventilation to totally cool a building. Where large numbers of people are contained within the building, such as in a mess hall or a theater, mechanical ventilation and cooling will be required to offset the heat gain generated and to supply fresh air. Mechanical systems for desert construction will be discussed in a later section.

The size and placement of openings in building walls are critical because the solar intensity is very high. Any exposed opening will admit large amounts of heat. Since there is very little sky cover (cloudiness) in desert areas, diffuse radiation need not be considered and shades can be designed to stop only the direct radiation of the sun, as shown in Figure 57. Because of the large nighttime temperature drop, many buildings can be designed with little or no mechanical equipment, provided that they adequately circulate the cool, nighttime air. To do so effectively, large openings are needed with external shutters to protect these areas from heat penetration during the day and wind penetration during storms. Openings should be kept to a minimum in mechanically air-conditioned buildings because each square foot of glazing allows the infiltration of significant heat gains. It has been calculated that a sheet of glass transmits about eighty times as much heat as a well-insulated wall in arid regions.[39]

The most effective height of windows in terms of ventilation for human comfort ranges from 18 to 60 in. (46-152 cm) above the floor.[40] In sleeping areas it is advisable to keep the sill right at the height of the beds to insure an adequate airflow around this area. Whenever higher windows are required they should be of a horizontally pivoted type so that the window panel deflects the airflow down into the space (see Figure 58).

To keep building maintenance to a minimum, proper window types should be selected. Sliding glass windows have proven to be unsatisfactory because sand accumulates in the tracks during dust storms, necessitating frequent cleaning (see Figure 59). Horizontally pivoted (awning and hopper) and vertically pivoted (casement) windows have performed adequately in desert weather conditions and are recommended. Louvered windows, unfortunately, are slightly pervious to strong winds and allow dust to penetrate, so they are not recommended. When natural light but not ventilation is needed, shaded, double-pane, tinted, fixed glass is recommended.

Construction Practices

Surface Treatment. As mentioned in Chapter 3, the color of the building exterior determines to a great extent the amount of heat it gains. In desert construction the external wall material should have low absorptivity and should be painted white as shown in Figure 60. It has been found in an experimental building coated with whitewash that the wall surface temperature was actually lower than shade air temperature for most of the day.[41] Other research also indicates that proper color selection has a significant influence on the temperature inside a building.

Wind Considerations. Duststorms occur fairly frequently in desert areas, producing a sandblasting effect on structures. For this reason the durability of the exterior wall finishes becomes important to the overall weatherability of the building. Coatings for different wall materials will be discussed in a later section of this chapter. The wall systems must be designed to take the full wind load recommended. Horizonal or vertical reinforcements are frequently used to strengthen certain types of walls such as adobe or concrete block. Free-standing or protruding wall elements are very vulnerable and must be tied together and anchored well.

Pest Control. Solid wall construction is subject to settlement and temperature cracks which, unless fixed, will allow termite infestation. At locations where there are termite problems, cavity wall construction requires the use of termite shields at the base of the wall and fine screening over all vent openings. Frame-and-panel wall construction requires no special considerations other than to make sure that all panel seams are adequately sealed. On operable windows and panels, screens should be used when needed. Their use should be limited because they will result in a much lower airflow through the building (as much as 50 percent less).

Insulation. A layer of insulation should be placed on the outside of heavy solid or cavity walls to protect the

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[39] B. S. Saini, *Architecture in Tropical Australia* (Melbourne University Press, 1970), p 29.

[40] B. Givoni and M. E. Hoffman, "Effect of Roof Design on Indoor Climate in Hot Arid Zones," *Build International*, Vol 6, No. 5 (1973).

[41] M. Danby, "The Design of Buildings in Hot-Dry Climates and the Internal Environment," *Build International*, Vol 6, No. 1 (1973), p 63.

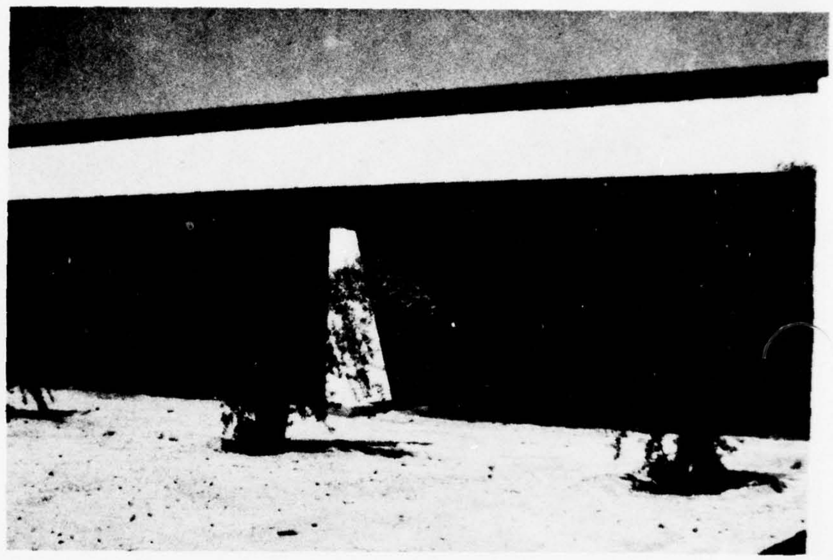

Figure 57. Shaded windows and wall.

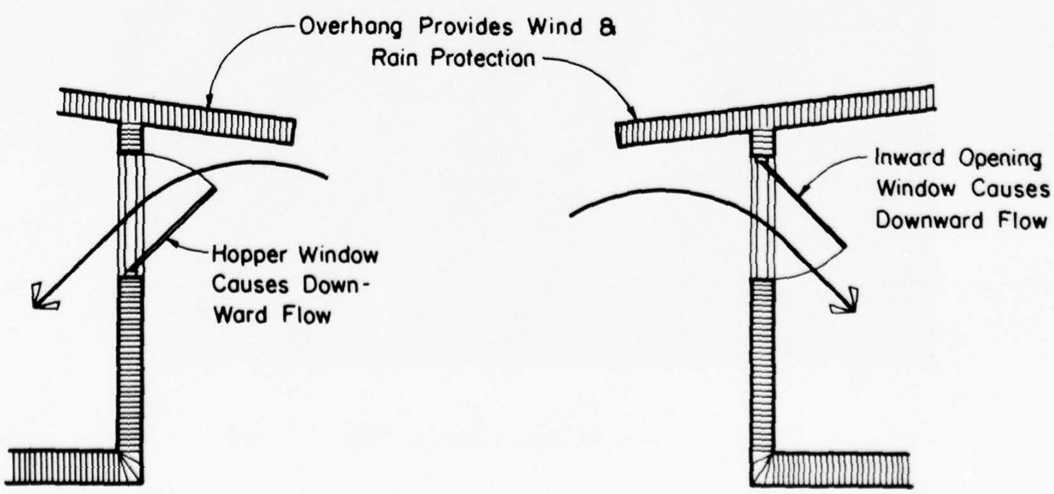

Figure 58. Hopper window placement.

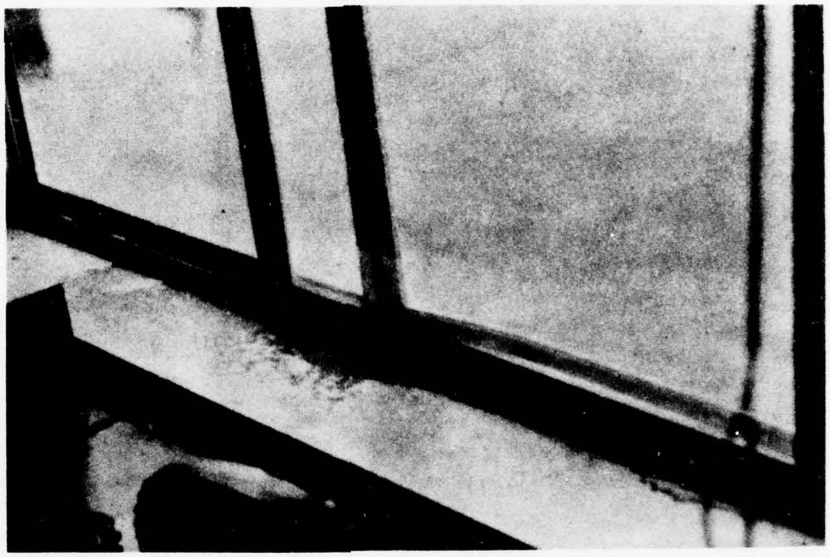

Figure 59. Sliding window dust accumulation.

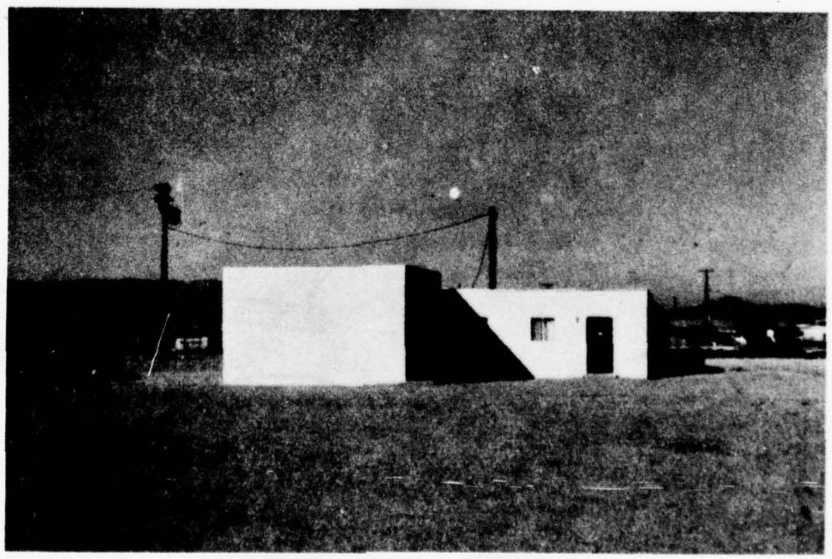

Figure 60. Light-colored building.

walls from heating excessively. This insulation will limit the effects of expansion and contraction forces and also can allow the walls to retain the coolness they can gain at night by ventilation. The type and thickness of insulation used will be determined by the heat lag desired.

Panel-and-frame walls must include a good layer of insulation because having no mass they transmit heat very quickly. If shutters are used to cover windows and other openings, they will probably be similar in construction and should be insulated in the same manner. The thickness and type of insulation is dependent on the heat resistance needed.

Masonry Wall Crack Control. Masonry wall cracking can occur for several reasons: foundation movement, lateral forces, movement of other building elements to which the walls are attached, temperature effects, and shrinkage due to moisture loss and carbonation.[42] The main effects of the arid climate are increased temperature differentials and larger unit shrinkage values. Temperature effects can be reduced by providing shade for the wall areas, using insulation as discussed above, providing mechanical cooling, and increasing the reflectivity of the wall materials. Shrinkage cracking of concrete masonry units is a major problem in arid climates because of the low relative humidity. To control shrinkage cracking, the use of moisture-controlled blocks (ASTM C90-70 Type 1) should be specified. Doing so limits the moisture content of each installation to not more than 25 to 35 percent, depending on the total linear shrinkage potential of the units.

Some methods of minimizing wall cracking due to shrinkage and temperature are to:

1. Provide vertical control joints in the walls. Proper spacings based on experience in Saudi Arabia are listed in Table 5.

2. Use mortar which has high tensile strength characteristics.

3. Reinforce horizontal joints.

4. Use bond beams at appropriate locations in the wall.

[42]LeMessurier Associates/SCI, *Investigation of Cracking in Structures, King Abdul-Aziz Military Cantonment* (1974), p 122.

Shrinkage cracking of brick masonry walls is not a problem, so control joints need not be used. Expansion joints are recommended through all structures which exceed 200 ft (60 m) in the longest dimension.

Care must be taken to insure that masonry walls are not restrained from moving by other building elements. The difference in materials and temperatures will often cause differing rates of expansion and contraction for the wall and the other elements. Stresses will then build up until released, in most cases, by the wall cracking.

Material Usage

Structural Wall Members. Concrete is an excellent material for wall construction in general. Its large heat capacity and low conductance values can be used to advantage if properly applied. The problems with using concrete are in the placing and curing processes, as discussed in Chapter 5.

Concrete masonry is in many respects similar to concrete and is acceptable as a wall material for arid construction. It is, however, affected strongly by solar radiation during the construction process, as the heat quickly drives off the moisture in the mortar and creates a weaker bond strength.[43] This problem is generally remedied by adding extra water to the mix. Concrete masonry walls are subject to cracking once in service, as discussed above, and require proper detailing to insure that no problems develop.

Brick masonry is very similar to concrete masonry as a wall material but has a few different properties. It is a dense material like concrete but is not subject to shrinkage. It must be designed for expansion forces, however. The construction process is affected strongly by solar heat in the same manner as is concrete masonry construction.

Adobe and rammed earth walls are often used in arid regions. Because of the low humidity and lack of rain, these walls will remain fairly intact without any stabilizing materials. The use of binders to strengthen the blocks or walls is recommended to increase resistance to the abrasive effects of the wind.

Frame walls are not normally used in arid regions. Wood framing warps and checks severely when exposed

[43]NAHB Research Foundation, Inc., *All Weather Home Building Manual* (U.S. Government Printing Office, 1975), p 104.

Table 5
Concrete Masonry Wall Joint Placement*

Maximum Spacing of Control Joints**,†	16 ft (5.0 m) or 2.0 H	20 ft (6.0 m) or 2.4 H	23 ft (7.0 m) or 2.8 H	26 ft (8.0 m) or 3.2 H
Vertical Spacing of Horizontal Joint Reinforcing††	No Reinf.	24 in. (60 cm) c-c	16 in. (40 cm) c-c	8 in. (20 cm) c-c

*From LeMessurier Associates/SCI *Investigation of Cracking in Structures, King Abdul-Aziz Military Cantonment* (Unpublished, 1974), p 130.

**Table is based on use of ASTM C90 Type 1 moisture-controlled masonry units.

†Spacing shall not exceed the smaller of the dimensions shown. H = height of wall panel.

††Joint reinforcement shall include 2 or more longitudinal steel wires, minimum total area = .0346 sq in. (.223 cm^2).

to direct sunlight and low humidity. Sand and dust seepage from daily winds also creates problems in frame construction because sand and powdered dust penetrate any unsealed crack or crevice. Steel and aluminum framing members are suitable, but the high daytime temperatures may make these materials too hot to handle.

Claddings. Lightweight wall construction is practical if the framing problems mentioned above can be resolved. Galvanized corrugated metal sheets are satisfactory as exterior siding materials. Again, the heat absorbed by the panels during construction may make handling and installation difficult.

Baked-enamel steel panels appear to be suitable for wall construction. However, the durability of the enamel coating has not been established for desert exposures. The abrasiveness of the wind and the intense sunlight may cause the finish to deteriorate. If used, the panels should be finished with a light reflective coating.

Aluminum sheets are also a good cladding material for desert construction. High reflectivity (85 percent initially) and good weathering characteristics are the advantages offered. Aluminum does have a high heat storage capacity, which can cause handling problems, and it is very noise in storms.

Asbestos-cement sheets are satisfactory for exterior siding if installed properly (Figure 61). Asbestos-cement shingles without proper backing, however, are too fragile under high wind and dust storm conditions and should not be used as a siding material.

Stucco is suitable as a cladding material, but the application process is strongly affected by the heat. The large areas of stucco exposed to the hot, low-humidity air allows rapid loss of moisture by evaporation. Unless the moisture lost is replaced, the chemical curing process will not continue and the stucco will not seal properly.[44] Because of this moisture problem and the long application time required (21 days) stucco wall finishes are not recommended for desert applications.

Fiberglass corrugated sheets are very durable in hot-weather construction and are suitable as siding panels if they are adequately supported. Other types of plastic sheets and panels are variable in their performance under the extremes of heat and low humidity.

Because of its poor weathering characteristics, wood is not recommended as a siding material for permanent construction in deserts. Its main faults are dimensional instability, checking and cracking, and poor paint holding qualities (Figure 62).

Wall Opening Inserts. Double-pane reflective glass is recommended for general use to minimize the transmission of heat. In air-conditioned buildings where the temperature differential is large, triple glazing may be considered if economically feasible and locally available. Window shutters should be heavily insulated panels made of one of the cladding materials suggested above. Clad aluminum alloy screen is recommended for general

[44]NAHB Research Foundation, Inc., *All Weather Home Building Manual* (U.S. Government Printing Office, 1975), p 97.

Figure 61. Asbestos-cement wall panels.

Figure 62. Disintegrating paint on wood siding.

use. Screens should be either a number 16 or 18 mesh and should be attached to the frame with continuous perimeter splines.

Exterior doors should be heavily insulated and well sealed. In air-conditioned buildings, vestibules may be used to reduce infiltration heat gains and dust penetration.

Summary Recommendations

Permanent Buildings. Whenever possible, heavy solid or cavity walls should be used for permanent construction. They provide excellent protection if properly insulated, and the ability to use the heat stored in the walls for nighttime heating is a strong advantage. Concrete is the best material available, but it does require special attention during the placing and curing processes. All wall openings should be well sealed and protected from the sun and heat by overhangs and shutters. The external wall finish should be reflective: a metal or white finish is recommended for isolated buildings, and light, subdued finishes should be used in urban settings.

Temporary Buildings. Heavily insulated lightweight wall systems are recommended over the heavier solid and cavity walls because of significantly shorter erection times and comparable insulating qualities. Exterior finish requirements and wall opening considerations are the same as for permanent construction.

Roofs

Design Considerations

Roof design in desert climates is based on differing and somewhat conflicting premises from those on which tropical roofs are designed. Physical comfort in the desert depends primarily on protection from direct and reflected solar radiation. Given sufficient protection, the human body can be cooled by radiation of body heat, evaporation due to low ambient relative humidity, and, in certain cases, convection. The relatively large diurnal temperature change in desert climates is the principle characteristic which influences roof design. Roofs are designed to protect the interior during the day and then cool off during the evening.

Traditional roofs in desert climates are heavy, thick, and dense. The lag between the time when the roof starts to store heat and when it gives the heat off is variable. The time lag depends on the thermal absorption and conductance properties. Once the material is chosen, the thickness of the roof determines the amount of time it takes for the heat to penetrate inside.

When a building is used only during the day (for example, an office), the roof thickness may be reduced, resulting in a shorter time lag. A time lag of four to six hours may be needed to insure that the passage of heat is delayed until the building is unoccupied. A longer time lag of nine to twelve hours may be required when the building is occupied 24 hours per day to insure that heat emission to the interior is delayed until the time of lowest evening air temperature.[45]

Roof reflectance plays an important role in desert facilities just as it does in the tropics by reducing the amount of heat absorbed by the roof. White or shiny metallic surfaces are recommended. Whitewash may be the best method, but it does require extensive maintenance, as evidenced by Figure 63. As in the tropics, there must be a similar concern for maintenance of a high level of reflectance. In the desert, however, the problem is one of wind-borne dust. Along coastal areas, corrosion and other effects of humidity will be of concern.

The thermal resistance afforded by insulation can be used advantageously in the desert to maintain natural cooling. Insulation can be used in thick roofs to provide a separation between hot and cool surfaces in a layered construction. Insulation can also be used on the exterior roof surface of thinner roofs to increase thermal time lag.

In the design of heavy monolithic roofs, or roofs of a material dissimilar to that of the wall, movement induced by thermal contraction and shrinkage must be carefully considered. This problem is serious in concrete structures where the roof and wall are tied together structurally.

Wind affects desert roofs similarly to tropical roofs. Flashing details are especially important, as the desert wind tends to blow off poorly attached roofing (see Figure 64).

In summary, the design of a satisfactory roof is dependent on the designer's accurately pinpointing the actual climate for which the building is being designed. Desert climates vary significantly, ranging from hot-dry to hot-humid coastal areas. The climate also influences the selection of roofing materials and construction methods.

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[45] O. H. Koenigsberger, et al., *Manual of Tropical Housing and Building, Part One: Climatic Design* (Longman, 1973).

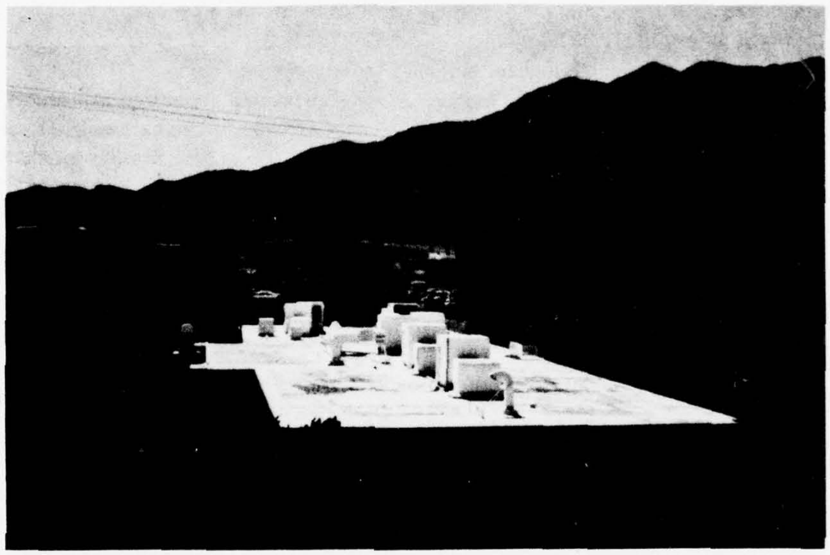

Figure 63. Whitewashed roof.

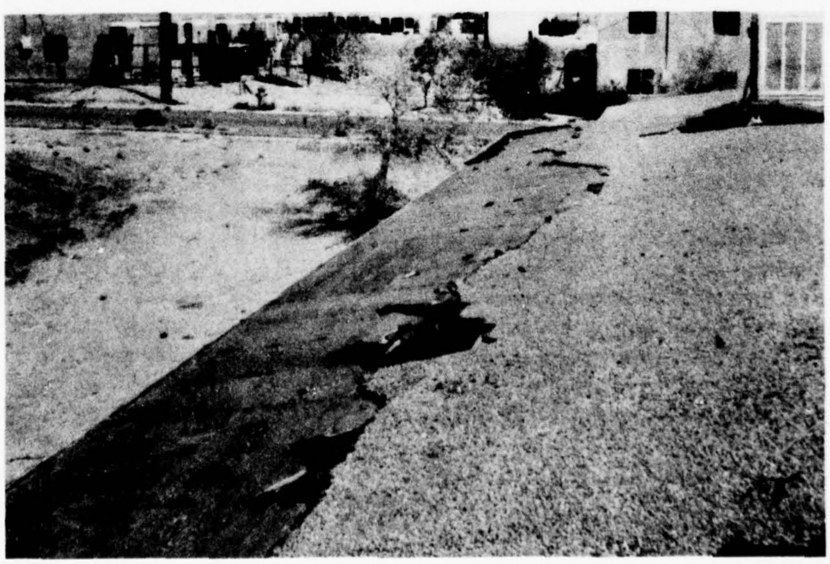

Figure 64. Roof blowoff.

Construction Practices

Traditional roofs in desert climates are flat, providing maximum exposure to solar incidence but also maximum emission of heat to the cooler night air. In addition, flat roofs provide another living area when interior temperatures remain too high for sleeping. For permanent buildings, roofs will most likely be heavy in an effort to store heat. Temporary or semipermanent buildings like the one pictured in Figure 65 will have roofs of lighter construction, relying almost exclusively on reflectance and resistance insulation to maintain lower interior temperatures. By eliminating windows and minimizing the number of entrances, the interior of this type of building can be kept fairly comfortable by using evaporative coolers. In either case, the roof thickness can be reduced by layering roofing materials to make use of differing thermal characteristics. Evaporative cooling is also an effective alternative for flat roofs where water is available at low cost; ponding or spraying both appear to be useful.[46] Another related method developed by Givoni and Hoffman[47] involves using layers of aggregate cooled by spraying (see Figure 66). Evaporation from a roof spray occurs in the course aggregate, and cooled air sinks below that layer. Both evaporation and the white layer reduce heat buildup. The spray can be turned off at night to encourage radiation cooling.

Sloped roofs have not found wide usage in the desert. Ventilation of the space beneath a sloped roof appears to be questionable, although sufficient data regarding ventilation rate are not available to eliminate this alternative.[48] When nonmechanical venting (such as a turbine vent) is available, a forced draft can be created which will draw air below the roof. Even though the air temperature is higher than desired for interior comfort, it will still be lower than the roof temperature. A ceiling or second roof layer will be necessary to maintain reduced interior temparatures in such a case.

Double flat roofs appear to be gaining increased usage in new, permanent construction. The outer roof serves as a shading and reflective surface for the roof below. In addition, temporary and permanent roofs can and should shade as much of the wall and outside ground area around the building as possible. Double roofs can also be adopted for lighter temporary buildings as described for tropical climates, but costs may be considerably higher. To reiterate, the outer surface provides shade and reflectance, an inner air space is ventilated to remove heat, and the second layer or ceiling is fashioned from insulating material and a reflective surface facing the air space.

Material Usage

Corrugated galvanized iron is suitable for temporary roofing when it can be adequately coated for reflective purposes. In coastal areas it should be used only where it can be protected from corrosion.

Aluminum sheeting is appropriate for similar reasons, although the reflective surface can be damaged by the scouring action of dust-laden winds or the reflectivity may be reduced through a buildup of dust.

Connections attaching the sheet metal roofing should permit a considerable amount of thermal movement to allow for temperature changes. Movement should not be transmitted to structural supports.

When concrete is desired for permanent construction, certain roofing systems are preferable to others. The most satisfactory system uses a maximum number of components which are free to individually shrink over time without transmitting forces over the entire roof. Precast elements have served satisfactorily to cover the roof. Cast-in-place concrete is also satisfactory if enough expansion joints are provided. Conscientious concrete roof design can prevent many roof problems. Work by LeMessurier Associates (SCI)[49] for the Corps of Engineers has produced a reasonable design tool and set of considerations for concrete roofs in desert climates. This work is recommended as a reference source.

Conventional built-up roofing systems should be covered with white or light-colored aggregates to reduce solar radiation. If painted, the roof coating will have to be periodically renewed to insure reflectance. Figure 67 shows how whitewash weathers away. Asphalt used for the built-up roofing should be of a high-melt type.

Other roofing materials such as asbestos-cement or clay tile will serve adequately as long as they are protected from breakage during installation and are whitewashed to reflect solar radiation.

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[46] G. Lippsmeier, *Building in the Tropics* (Verlag Georg D. W. Callwey, 1969), p 162.

[47] B. Givoni and M. E. Hoffman, "Effect of Roof Design on the Indoor Climate in Hot Arid Zones," *Build International*, Vol 6, No. 5 (1973), p 535.

[48] Givoni and Hoffman, p 531.

[49] LeMessurier Associates/SCI, *Investigation of Cracking in Structures, King Abdul-Aziz Military Cantonment* (unpublished, 1974).

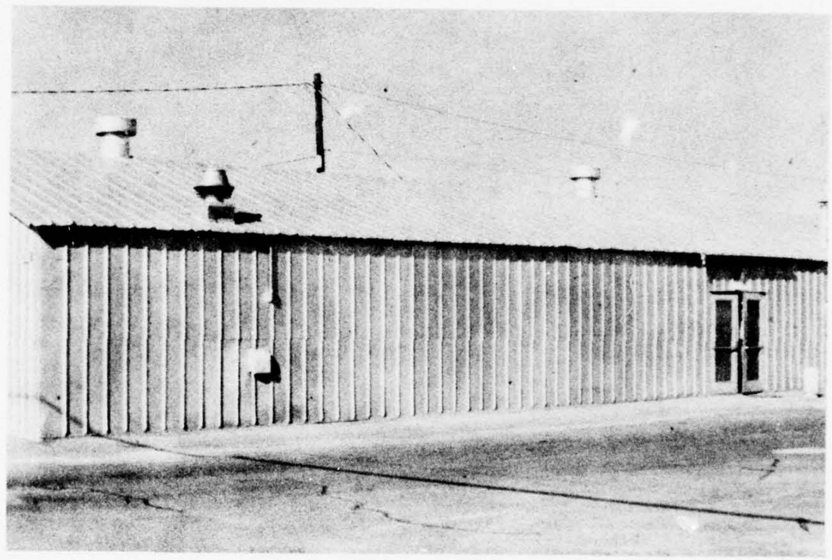

Figure 65. Lightweight reflective building.

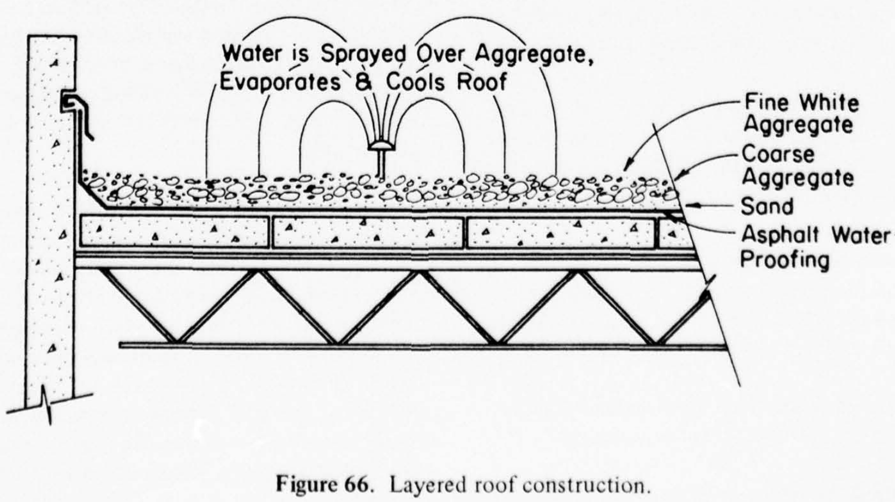

Figure 66. Layered roof construction.

Figure 67. Faded whitewashed roof.

Summary Recommendations

1. The designer should ascertain to the maximum extent the characteristics of the climate for which the building is being designed.

2. The exterior surface material should be white or whitewashed.

3. Permanent and temporary roofs should be designed in layers. Permanent roofs may have insulation as a replacement for an air space in temporary facilities.

4. If cast-in-place concrete is used for roofing, enough expansion joints should be provided. Smooth joints between the wall and the roof must be provided to allow this roof slab to move freely.

5. Aluminum or corrugated galvanized iron roofs should be used for temporary buildings, taking into account the need for suitable maintenance of the reflective surface and a second insulating layer below.

6. Air spaces of double-roof construction should be ventilated when dust problems can be minimized.

7. Eaves should be of the maximum length possible.

8. Asphalt used for built-up roofing should be of the high-melt type.

Interior Walls

Design Considerations

Interior walls in desert buildings are subject to few of the restrictions which apply to external walls. The two important weather elements of the desert climate, sun and wind, are both absent inside the building, so a wide variety of materials can be used. In air-conditioned buildings, any common wall material may be used. When naturally ventilated, building interiors are dried out by the low relative humidity. Hence, wood and other materials strongly affected by low humidity levels are not recommended.

Nighttime ventilation is a very good method of cooling in arid regions because of the large diurnal temperature range. Interior wall placement should provide for such ventilation. Because the building envelope is usually heavy, interior partitions are often bearing walls, severely restricting the benefits of natural ventilation by limiting air circulation. To provide sufficient ventilation, either the traditional vertical exhausts (wind chimneys) should be incorporated into the internal walls, or a central ductwork system should be provided to create an airflow.

Since interior walls are often structural, they can store the nighttime coolness if the interior is properly ventilated. The heat storage property of heavy building materials also allows them to store heat. This requirement is the major drawback to the natural method of cooling because if the occupants do not ventilate the building daily, the heat gains steadily accumulate, are stored in the interior walls, and cause the building to become excessively warm.

In the event that daily ventilation is not possible, the best wall system would be lightweight and would have very little heat storage capacity.

Construction Practices

The color of interior walls, floors, and ceilings determines to a large extent the amount of artificial light required during the daylight hours. Since natural lighting is very limited, the use of very light finishes is recommended to maximize light reflection. Also, the daylight that enters through the windows is very bright and can cause a discomforting glare unless wall areas around the openings are finished in light tones.

Material Usage

In air-conditioned buildings the choice of interior wall materials is subject to few limitations because the humidity can be raised to suitable levels. It is recommended, however, that materials which are strongly affected by low humidity levels not be used because they can become damaged in the event of a power failure or if natural ventilation is used at night.

Exposed concrete walls are suitable for the building interior because they do provide a large cooling storage capacity. Additionally, they can act as internal bearing walls to help carry the roof loads, and they offer good fire protection. Coatings used to finish concrete walls are discussed in a later section of this chapter.

Masonry is also good when a heavy internal wall is needed for thermal or structural purposes. Exposed brickwork usually needs to be painted to provide a light finish (see the section on paintings and coatings for suitable materials).

Gypsum board is generally too fragile to be used for interior partitions. When a lightweight wall system is needed, metal studs and metal or fiberglass panels are suggested. Wood studs, panelling, trimwork, and doors are not recommended because of their susceptibility to low humidity and termite attack. If used, all wood should be kiln dried to limit shrinkage and warpage.

Summary Recommendations

Interior walls for permanent facilities should be massive when adequate nighttime ventilation can be provided. The best materials for this type of wall are concrete and masonry. Lightweight walls and partitions should be used where daily ventilation is not practical and should be made of metal or fiberglass. Since wall partitions are flexible in placement, care should be taken to allow good ventilation around these obstacles.

Use of interior walls for temporary construction should be minimized because they limit the air flow. Where needed, they should be lightweight, light in color, and made of the materials suggested above.

Building Hardware

Current research on desert construction practices has not revealed any special considerations concerning the durability of various types of building hardware. However, some general assumptions can be made on the weathering of external hardware exposed to the sun's heat and the desert wind. High daily temperatures and low humidity should not seriously affect the operation of various hardware parts. Wind causes the only problem because it carries dust and sand which abrade and penetrate all building components exposed to it. The effects of abrasion can be minimized by specifying brushed metal finishes for all exterior hardware. Penetration and accumulation of dust and sand into hardware mechanisms will cause a loss of lubrication. Generally this is remedied by periodic maintenance. More mechanically complicated hardware such as cylinder locks should not be used in exposed locations because they present more maintenance problems.

Electrical Equipment

Desert environments do not seriously affect the installation and maintenance of electrical systems. There are some special provisions, however, which are listed below.

1. In the past intense desert sunlight has caused the structure of plastic-coated cables to break down, drastically lowering their durability. Some plastic coatings recently developed (within the past 5 to 10 years) do not deteriorate and are acceptable. All plastic-coated cables used must be sheathed with the newer type of plastic to insure adequate service.

2. Larger conductor sizes than those normally used in temperate climates are required to provide the same current-carrying capacity because of the higher ambient temperatures. See Article 310 of the National Electrical Code for specific sizing requirements.

3. All external equipment must be dustproof to prevent the accumulation of dirt. The extra material costs should more than offset the savings in maintenance.

4. Pest damage to underground cables can be severe in certain locations. Abrasive coatings, metal shields, and chemical treatment are all effective methods of providing protection.

5. All electrical outlets should be compatible with locally available appliances.

Mechanical Systems

Forced Ventilation

Circulating and exhaust fans have limited potential for providing daytime comfort in hot arid regions. Cross ventilation or air movement when temperatures exceed 98°F (37°C) may result in a net heat gain, as mentioned previously. Daytime comfort is usually dependent upon the mass of the building absorbing the heat of the day or on mechanical cooling.

Nighttime ventilation is extremely important, as the cool night air can be used to exhaust the heat from the building and also to provide comfort for the inhabitants. Exhaust or attic fans can be very effective in providing a large enough airflow to cool a building if located in a central position in the ceiling or attic. Australian tests showed that where the diurnal temperature range exceeded 20°F (11°C) the rate of temperature drop in a house using an attic fan was twice that which occurred as a result of natural ventilation.[50] By properly sizing the fan to remove the internal heat gain stored in the building mass, indoor temperatures dropped to a level close to the outdoor temparature and provided a comfortable environment.

Any type of ducted ventilation or air-conditioning system will require a filtration unit to prevent excessive dust accumulation. If the mechanical system is used during the day, especially in the late afternoon when large amounts of dust are suspended in the air by winds, the filters will require frequent periodic maintenance. If possible, mechanical systems should be used primarily at night to reduce dust infiltration and maintenance problems.

[50] E. T. Weston, *Ventilation and Cooling of a House With an Attic Exhaust Fan*, Special Report #9 (Commonwealth Experimental Building Stations, Sydney, Australia, 1972).

In hot dry areas the relative humidity is very low, and the cooling effect of evaporating water can be used to reduce indoor temperatures significantly. Evaporative coolers take advantage of the latent heat of vaporization of water to provide cooling. This system has been used in hot arid countries for centuries. Mechanized versions of such a system are now packaged and sold commercially as room-sized or larger central units. Evaporative coolers are relatively simple in construction; the components are a circulating pump, an evaporation chamber, and a fan. This system is very economical in that it provides cooling (10 to 20°F or 6 to 11°C temperature reduction) comparable to that of conventional air conditioners at about one fifth the cost. The effectiveness of a cooler depends heavily on the daily relative humidity. Approximate temperature drops for different relative humidities are given in Table 6.

Some limitations of this type of cooling must be mentioned. During periods of high relative humidity such as the wet season the evaporation system cannot work effectively. However, the cooler can still work as a straight ventilation system and provide a degree of comfort.

In some localities the availability of clean water is restricted, another limitation to the usefulness of evaporative coolers. Nonpotable ground- and rainwater may be used if a filtration system is included to remove unwanted chemicals and foreign matter which otherwise would clog and corrode the system. Also, the noise level of the fan may be objectionable, especially in room units where in many cases the fan turns at a high speed. This noise problem can be overcome by using a larger fan operating at a lower speed or by using a central system located away from habitable rooms.

The cooled, moist air must be exhausted from the interior fairly quickly to prevent the relative humidity

Table 6
Temperature Reduction by Evaporative Cooling*

Dry-bulb	Relative Humidity			
Temperature	10%	20%	30%	40%
100°F	23°F	19°	15°	13°
95°F	20°	18°	14°	12°
90°F	19°	16°	15°	11°

*J. Playnter, "Evaporative Cooling—the Principles Involved and Their Application to Building in Western New South Wales," *Architectural Science Review*, Vol 7, No. 3 (1964), p 110.

from building up. Consequently, part of the cooling potential is lost since the air exhausted is still fairly cool. To solve this problem a more efficient adaptation (known as regenerative evaporative cooling) has been developed to capture the cooling capacity of the used air by the use of a rotary heat exchanger[51] (see Figure 68). This system does require more mechanical equipment and has a higher initial cost, but savings over the simpler evaporative cooler should be realized over the life of the unit.

Air Conditioning

In general, the considerations listed in Chapter 3 for air conditioners in tropical applications hold for desert areas also. The use of a vapor barrier is not as critical since the outside air is normally low in humidity, but in areas where seasonal humidity levels can become high a vapor barrier should be used.

High humidity levels should not normally occur in the building interior as long as refrigeration air conditioners are used (assuming that they are sized correctly) because they act as dehumidifiers. In fact, humidification may be required in locations where the ambient relative humidity levels are extremely low (10 to 25%) because even when the air is cooled to between 70 and 75°F (21 to 24°C) the relative humidity may only be from 25 to 40% depending on the outside air temperature. In these locations, evaporative coolers should be used instead.

The discussion of room units in Chapter 3 applies to desert applications except that corrosion protection is not a big problem. Fan-coil units are acceptable because control of humidity is not critical. However, both of these types of room units will require an extensive filtration system to keep dust and sand out; otherwise, the units will be very prone to maintenance problems.

Central refrigeration air conditioning systems are preferrable in arid regions because much less maintenance of equipment and the building in general should be required if a good filtration system is employed.

Heating

Heating should not be required for facilities in arid regions if the building materials selected have good heat-storage capacities. Instead of ventilating the building interior at night, the building should remain closed to keep the heat in. If this passive solar heat storage technique is not feasible or adequate, conventional heating systems can be employed, as explained in Chapter 3.

Summary Recommendations

1. Nighttime forced ventilation should be used to remove the heat from the building.

2. Filtration systems are required to prevent dust penetration and accumulation in the mechanical equipment. The filtration elements must be cleaned or replaced periodically.

3. Evaporative coolers should be considered whenever air conditioning is necessary and the ambient relative humidity is below 40%. The availability of clean water and the variability of the ambient humidity are determinants in the acceptibility of an evaporative cooling system.

4. Because of filtration requirements, centralized systems are recommended over individual room units.

Plumbing

Plumbing installation in desert areas entails no special provisions beyond those practiced in temperate regions. Nevertheless, it must be cautioned that water pipes should not be exposed to the weather without proper insulation since the temperature in desert regions may drop below freezing during cold nights. The high alkali content of the water normally found in desert regions causes corrosion problems in water distribution systems and air cooling units (Figure 69). Cast iron water pipes must have proper linings to prevent corrosion. To reduce corrosion in the air-cooling units, water must be pretreated to remove undesirable minerals. One other consideration which could be important in locations where there are expansive soils would be to lay the piping in properly bedded trenches to prevent local rupture due to soil movement.

Paints and Coatings

General

In a desert climate it is especially important to insure that the entire coating system is compatible through each layer from the substrate to the surface. Any incompatibility will reduce adhesion and accelerate deterioration. Proper preparation of the substrate is also critical to the success of the coating system. The surface preparation techniques given in TM 5-618 for various substrates should be followed.

[51] B. S. Saini, *Architecture in Tropical Australia* (Melbourne University Press, 1970), p 79.

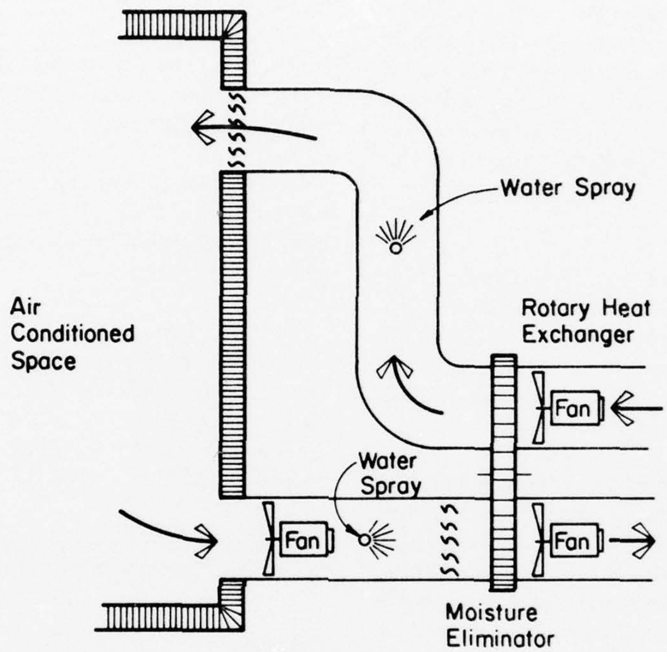

Figure 68. Rotary heat exchanger.

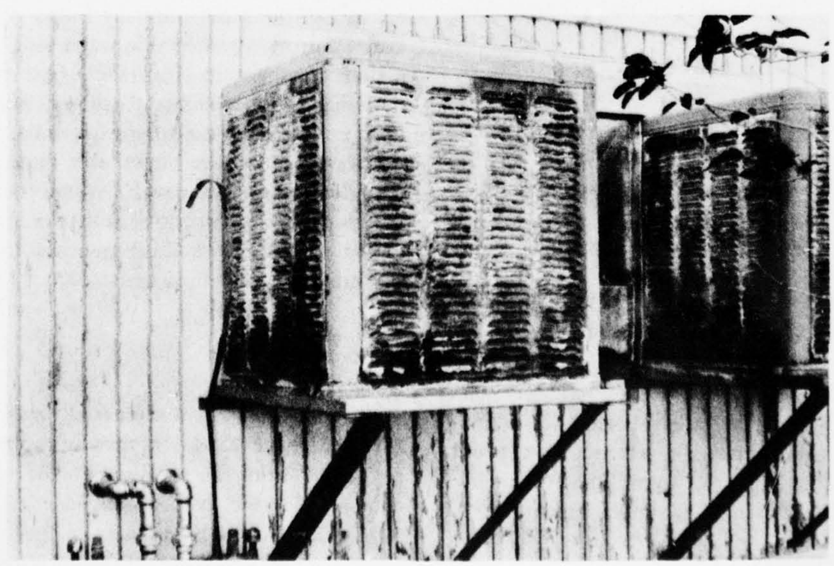

Figure 69. Corrosion of air-conditioning units.

The hot climate also affects paints during storage because settling and thickening of water-thinned paints are accelerated by high temperatures. TM 5-618 should also be consulted for information on storage considerations.

Certain coastal desert areas may be subject to periodic high ambient humidity levels which are favorable to mold growth. Also, since many building interiors are air conditioned, there is a possibility that mold and mildew will develop inside if the system is not properly designed. Refer to Chapter 3 for recommendations concerning fungicide applications.

Interior Coating Systems

Interior painting should not require any special considerations or application techniques.

The prevention of dust infiltration and the presence of high room temperatures are constraints which painters normally face and offer no serious problems. Spaces should be conditioned if possible to provide temperature and humidity conditions which will allow the paint to set up properly. Recommended interior paint systems based on past experience are listed in Appendix E, Table E2. Refer to Corps of Engineer Manual CE-250 for further explanation of recommended paint systems.

Exterior Coating Systems

Exterior coatings applied in hot dry climates are usually exposed to an atmosphere which is destructive in three ways. The intense sunlight and high daytime temperatures cause physical, chemical, and photochemical deterioration of the paint film surface. Painting in direct sunlight should be avoided because the paint will dry too quickly and set prematurely. Some paint manufacturers recommend the addition of a drying retarder to reduce this problem.[52] In any case, only small areas should be painted at a time in hot weather. Metal surfaces should not be painted in sunlight because they become extremely hot, and painting will result in flash-off and uneven flow and coverage. Oil-based stains should not be applied when temperatures exceed 90°F (32°C) or in direct sunlight.

Cementitious paint (TT-P-35) is also strongly affected by high temperatures or low humidities. It should not be applied where the ambient temperature is above 85°F (30°C) or where the relative humidity is below 40%.[53]

The variation between day and night temperatures causes large expansion and contraction forces to build between the coating and the substrate. This action typically results in checking, cracking, flaking, and peeling. This problem is most prevalent where paint is applied over wood substrates because of most wood's water absorption and thermal expansion properties. Wood in desert areas, as Figure 70 shows, should not be painted, because of its poor paint-holding qualities.

Rapid temperature drops overnight may cause a heavy dew or even frost to accumulate on the paint film. This moisture can retard the drying of newly painted surfaces and cause flatting of cured paint films. To insure proper application, the temperature of the substrate surface and of the ambient air must both be above 50°F (10°C) for water-thinned coatings and 45°F (7°C) for all other coatings.[54]

Desert winds cause deterioration of an external coating system in two ways. At high temperatures a breeze will cause rapid evaporation of the thinner, resulting in difficult application. In addition, rapid setting of the paint film often takes place and causes the formation of a skin which prevents proper drying. The common result is a coating with impaired durability, leading to a need for recoating. Wind also carries sand and dust which accumulate and destroy the finish on newly painted surfaces or abrade cured painted surfaces.

For the above reasons, exterior painting should be held to a minimum. Whenever possible, prefinished cladding materials or exposed precolored concrete and masonry should be used to enclose the building.

For reference, a list of paint systems for a recently constructed facility at the Yuma Proving Grounds is included as Table E2 of Appendix E. Table E2 is an abbreviated list taken from CE-250. The latter document should be consulted if further information is needed.

Summary Recommendations

1. TM 5-618 should be used as a reference for general painting procedures, including storage of materials and surface preparation.

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[52] NAHB Research Foundation, Inc., *All Weather Home Building Manual* (U.S. Government Printing Office, 1975), p 107.

[53] *Guide Specification for Military and Civil Works Construction Painting, General*, CE 250 (Department of the Army, 1968), p 12.

[54] *Guide Specification*, p 22.

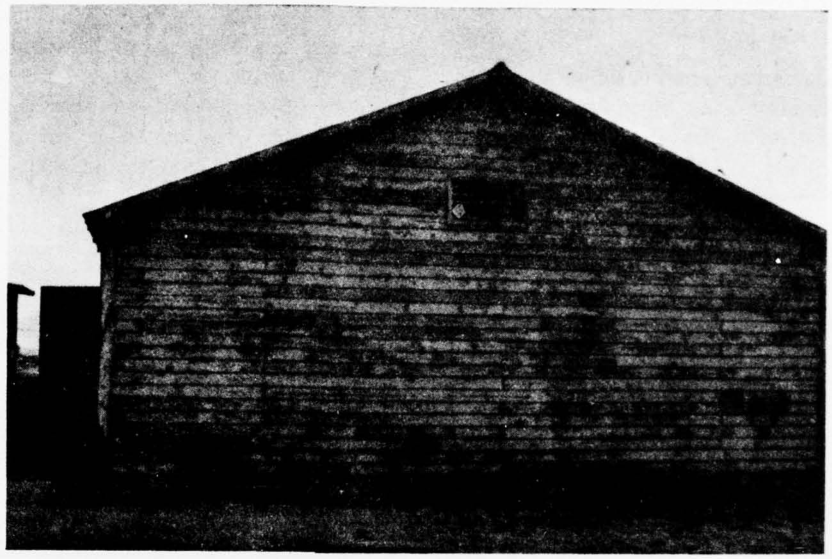

Figure 70. Deteriorated paint.

2. Where high humidities or moisture problems are encountered, a fungicide must be incorporated into the paint. See the paints and coatings section of Chapter 3 for details.

3. Recommended interior and exterior paint systems are given in Appendix E, Table E2.

4. Building surfaces should not be painted in direct sunlight, as the paint will dry prematurely and not cure properly.

5. Metal surfaces should not be painted when they are extremely hot. Oil-based stains should not be applied when temperatures exceed 90°F (32°C) or in direct sunlight. Cementitious paint should not be applied when temperatures are above 85°F (30°C) or the relative humidity is below 40%.

6. The rapid temperature drops which commonly occur in desert areas can retard the drying of newly painted surfaces. When large temperature drops are anticipated, adequate protection should be provided.

7. Newly painted surfaces may require protection from the wind to prevent premature drying. Protection is also needed to prevent finish damage by dirt accumulation or abrasion.

8. The use of prefinished cladding materials or precolored masonry is recommended whenever possible to minimize exterior painting.

5 UTILITY OF VARIOUS CONSTRUCTION MATERIALS IN TROPIC AND DESERT REGIONS

Structural Steel

Materials

For locations subject to severe atmospheric corrosion the use of high-strength, low-alloy structural steel such as ASTM A242 and A441 or high-strength steel such as ASTM A440 may be advantageous. The atmospheric corrosion resistance of both A440 and A441 is approx-

imately twice that of structural carbon steel. A242 steel has enhanced atmospheric corrosion resistance at least twice that of structural carbon steel. Certain steels in the A242 group have corrosion resistance up to six times that of structural carbon steel. The designer should specify the type of high-corrosion-resistance steel required. Although such steels have a higher initial cost, this difference may be offset by the savings in maintenance during the life of structures. Nevertheless, the standard A36 structural steel is generally more economical than high-strength steel and does perform satisfactorily if it can be well protected or is covered with a proper coating system.

Weathering steel (A242 and A588), designated by trade names such as Corten or Mayari, should be used selectively in tropical environments. This type of steel relies on exposure to the atmosphere for formation of protective oxide layers and needs several distinct dry and wet cycles to develop these protective layers. Uncoated weathering steel should not be used in locations where it will be exposed to concentrated industrial fumes, in marine locations where salt can be deposited on the steel by either spray or fog, or where the steel is either buried in soil or submerged in water.

Construction

Structures should be designed to eliminate or minimize concealed or inaccessible surfaces subject to corrosion. Surfaces of the structural steel used should be cleaned and shop-primed using red lead or zinc chromate prior to shipment. Sandblasting at the shop is not warranted since shop priming alone is not adequate to prevent corrosion during the time required for shipment and erection. However, sandblasting in the field is needed in almost all cases before the application of a coating system. A service-proved finish coating system that meets appropriate specifications should be applied as soon as possible after the surface is properly prepared.

Steel columns embedded in concrete should be coated with coal-tar enamel, covering the embedded section to a point 6 in. (15 cm) above the concrete surface.

Steel piling driven in harbor areas for permanent construction should be encased in concrete from 2 ft (61 cm) below the mean lower low water line and above. Steel sheet piling should be capped to retard corrosion at the upper ends. Without capping, the top becomes sawtoothed in 6 to 10 years. Steel corrodes seriously above the mean lower low water line. A coal-tar epoxy coating will protect the piling for about 3 years.

Concrete

General

Hot weather introduces problems in manufacturing, placing, and curing portland cement concrete, adversely affecting the properties and serviceability of the hardened concrete. In the absence of special precautions, hot weather may produce problems such as an increased water demand for the required consistency, difficulty in controlling entrained air, rapid evaporation of the mixing water, or rapid slump lot. Recommended practices to alleviate problems caused by hot weather can be found in "Recommended Practice for Hot Weather Concreting" published by ACI committee 305-72. Several additional preventive measures that are necessary and peculiar to certain areas in desert and tropic regions are given in the subsequent sections.

Materials

Cement. Portland cement should conform to specification ASTM C150-76A and should be of the following types for the designated uses, if available:

Type I – General-purpose cement suitable for normal use in concrete and cement plaster.

Type II – Modified portland cement with lower heat of hydration than Type I. Suitable for waterfront structures in contact with sea water.

Type III – High-early-strength cement; should be used in waterfront structures only if tricalcium aluminate is limited to 8%.

Type IV – Low-heat portland cement suitable for use where the amount and rate of heat generated must be kept to a minimum.

Type V – Sulfate-resistant cement suitable for subsurface harbor structures and structures exposed to concentrated sewage.

In some construction localities the use of foreign manufactured cement may be necessary. Although many foreign brands have previously been found satisfactory, they should be tested before use to determine compliance with specification ASTM C150-76a.

Note that high-alumina cement (high-early-strength cement) should not be used if chlorides are present in the mix, since they will interfere with the setting. The hydration reactions of high-alumina cement produce considerable amounts of heat. This heat can be very

difficult to dissipate even in cool climates with an ample supply of cold water. Hence, in warm climates, unless special cooling measures are taken, a loss in strength of the concrete will result. In addition, a loss of strength and of chemical resistance of the set concrete can occur whenever the temperature reaches about 97°F (30°C) in the presence of moisture. Therefore, the use of high-alumina cement is not recommended in hot climates except, perhaps, for temporary repair work.

When concrete is to be placed in the ground or near the ground where it is vulnerable to sulfate attack, the use of a sulfate-resisting portland cement (Type V) is advised.

Aggregate. Aggregates should consist of clean, hard, strong durable particles free of chemicals and of a coating of clay or other fine material that may weaken the bond with the cement paste. Weak, friable, or laminated aggregate particles are undesirable. Shale, stones laminated with shale, and cherts should be avoided. Visual inspection will often disclose weakness in course aggregate; if doubt exists, however, the aggregate should be tested.

Based on past experiences and investigation, coral has been used successfully in vertical construction as an aggregate for concrete in tropical islands.[55] If coral or similar materials are to be used as aggregates, they must be obtained from sources that provide the maximum hardness and specific gravity; the specific gravity should be above 2.5 if possible. Highly porous aggregates should be avoided. On coral atolls the most suitable material is usually found on the windward rim of the atoll near natural channels through the reef. The poorest material is usually found in the lagoon and on the leeward side. On larger islands, such as Guam, good aggregate material, such as compact coralline limestone, can usually be obtained from pits rather than by dredging. Aggregates should be processed and stockpiled as far in advance of use as possible to permit the rain to wash out the salt, particularly if the aggregate has been in recent contact with seawater. If necessary, the aggregate should be washed clean of dust and impurities, properly graded, and stockpiled to prevent contamination and to permit an accurate determination of moisture content at the time of mixing.

[55] P. Howdyshell, *The Use of Coral as an Aggregate for Portland Cement Concrete Structures*, Technical Report M-88/AD#784092 (Construction Engineering Research Laboratory, June 1974).

Fine Aggregate. The fine aggregate used should conform to the requirements of ASTM C-33. For coral aggregate concrete, the fine aggregate used should be manufactured from corraline limestone and obtained from approved sources. Gradation requirements are as given in Table 7.[56]

Coarse Aggregate. The coarse aggregate used should also conform to the requirements of ASTM C-33. Coral aggregate should be manufactured from coralline limestone obtained from approved sources and should be washed after crushing to assure proper bonding between the cement paste and the aggregate particles. The processed aggregate should be handled and stockpiled in a manner which will produce minimum segregation. Stockpiles should be built up in layers of uniform thickness and preferably should not exceed a total height of 6 ft (1.8 m) to reduce segregation. Rocks that contain soluble salt should not be used as aggregates for concrete mixes since they will increase the risk that the reinforcement material will corrode.

Mixing Water. No salt-laden coral sea water or brackish mix water should be used in the production of coral concrete in which reinforcing steel or conduit is to be embedded since rapid corrosion of the embedded materials is likely to occur.

Admixtures. Admixtures meeting ASTM C494-71 may be used. Type B, retarding, and Type D, water-reducing and retarding admixtures, have been found beneficial in offsetting some of the undesirable characteristics of concrete placed during periods of high ambient temperatures.

Construction

Proportioning. While proportioning by weight is desired, lack of equipment and extreme variability in the

Table 7
Aggregate Gradation Requirements

Sieve Size	Percent by Weight Passing
3/8"	–
#4	95-100
#8	75-95
#16	55-85
#30	30-60
#50	12-30
#100	5-10

[56] Howdyshell, *The Use of Coral*.

specific gravity and moisture content of aggregates in some areas make proportioning by volume necessary. Tests must be conducted to make sure that the proposed mix design will attain the desired workability and strength before commencing any actual construction work.

Mixing. Increased mixing time may be required if coral sand is used. The minimum time required to obtain uniformity throughout each batch must be determined for the mix and the mixer used. Nevertheless, mixing time should be held to the minimum to assure adequate concrete quality and uniformity because the temperature of the concrete is raised from the work of mixing, from the air, and from the sun. To reduce the effect of the hot sunlight on mixer surfaces, the mixer drums should be painted white and sprayed with cool water occasionally. Mixer drums and blades should be checked and washed frequently.

Delivery. The period between mixing, delivering, and placing the concrete should be kept to an absolute minimum.

Retempering. No water should be added other than that required to adjust the mixture to the specified slump within the limits of the specified maximum water-cement ratio.

Placing. In desert regions, high concrete temperature, high air temperature, high winds, and low humidity or any combinations of these can cause rapid evaporation and promote plastic shrinkage. Precautions are to dampen the subgrade and framework, to place the concrete at the lowest possible temperature, to erect efficient wind breaks and sunshades, and to promote early and efficient curing.

Curing. In hot weather water curing is much preferred to the use of curing compounds. However, it is recognized that prompt application of a white-pigmented liquid membrane-forming curing compound (ASTM C309-58) is more practical for curing vast areas of flatwork such as pavement and floor slabs. If water curing is used, the surface must be kept wet continually by covering all exposed surfaces (vertical, horizontal, and otherwise) with a water-saturated material such as burlap, or cotton mats. Alternate cycles of wetting and drying promote the development of pattern cracking and should be avoided.

Concrete Cover Over Reinforcing Steel. When coral is used as an aggregate for concrete, the minimum concrete cover over the reinforcing steel should be 2½ to 3 in. (5.0 to 7.6 cm) of high-quality, low-permeability concrete.

Reinforcing Steel

The corrosion of steel in concrete is a problem in tropical and marine environments, particularly where there is exposure to salt spray and to alternate wetting and drying. In the tropics, the unusually high humidity and extremely heavy rains, often accompanied by high winds, result in moisture penetrating the concrete and corroding the embedded steel. In a marine environment, every measure should be taken to ensure that loose salt and rust particles are removed from the steel before placing the concrete.

A sufficiently thick concrete cover over the main reinforcing steel is needed for protection from corrosive environments and for resistance to the expanding force of the corrosion product. The minimum concrete cover over reinforcing bars should be provided in accordance with ACI specifications (ACI 318-71). It is further recommended that the cover thickness not be less than twice the diameter of the largest aggregate used. Chairs and spacers should be made of a noncorrosive material such as plastic. For piles and similar waterfront structures extending below the water line, the minimum cover on main steel members should be 3 in. (7.6 cm).

Galvanized rebars have been found to stand up well in building use along the coastal region where high humidity and salt-laden air is found. It should be noted, however, that the mixing of galvanized rebars and uncoated rebars should be avoided to prevent galvanic action.

Wood

Material

Unless treated, wood performs very poorly in the tropics because of attacks by termites and fungi. Even with treatment, wood is still susceptible to attack since the treatment wears off after a certain period. Therefore, wood is not a good construction material for permanent facilities. If wood is required, it should be treated with preservatives. Two different types of treatment are available – pressure and nonpressure treatments. Pressure treatment is much more effective since it provides deeper penetration and longer retention of the preservative. Appendix B lists the commonly used preservatives and their properties along with recommended preservative treatments. Wood pressure treated with creosote is

not paintable, exudes oil when heated, and is dirty; hence, it is not suitable for interior use. However, this treatment method is the most durable and offers protection against decay, weathering, and moisture penetration. If paintability is required, the water soluble preservatives listed in Appendix B can be used for treatment in accordance with minimum standards established by American Wood Preservers Institute (AWPI).

The use of native wood species is highly recommended where available because of the cost advantage and the greater resistance that local species often have to attack by pests and mold. A short list of commonly used tropical timber varieties is offered in Appendix C.

Particle board should be avoided for construction in tropic regions because of its moisture absorbing property. If particle board is specified, such as for cabinet doors and drawers, it must be completely sealed, painted, and finished before shipment to the site.

In desert regions, the primary problem with wood is warping, twisting, checking, and splitting due to low humidity and direct solar heat. To reduce the loss of lumber due to warpage, kiln-dried lumber must be specified. As in tropic regions certain desert areas are also infested with termites, and pressure-treated wood will be required.

Construction

When designing structures using wood, the following practice should be followed: (1) wood should be kept from contact with the ground, and the lowest floor woods should be at least 18 in. (46 cm) above the ground on posts or piers; (2) adequate ventilation should be provided for wood members; (3) wide eaves should be provided to keep water away from the sides of buildings. Structures should be designed and constructed for rapid drying so as to avoid decay in joints. Unseasoned wood should not be placed in enclosed spaces, surrounded with concrete, painted, or otherwise prevented from drying quickly.

To reduce wood stud loss caused by warpage in desert regions, it is recommended that the studs be used as soon as the bands around the stud package are broken. The frame must then be wrapped immediately with paper-backed, wire-mesh stucco backing or some other material to shield it from the sun's direct rays. Another problem with using wood framing in a desert region is sand and dust seepage. To minimize this problem, all joints must be caulked, and weather stripping must be used.

Aluminum

Materials

Aluminum alloys, in general, last well in both tropical and desert climates. They provide high reflectivity to solar radiation and are little affected by aging. In addition, they are light and transportable. Nevertheless, it should be pointed out that not all aluminum alloys perform equally well under different tropical environments. Aluminum alloys with certain types of surface treatment perform significantly better than those without any surface treatment.

Based on the results of an atmospheric exposure test conducted in the Panama Canal Zone,[57] aluminum alloy (2024-T3) was found to have the highest corrosion rates in the marine environment. In some instances, catastrophic exfoliation corrosion of aluminum resulted. Rain-forest exposure generally produced less corrosion than occurred in the open field. It was found, however, that the corrosion of aluminum buried in the rain forest soil was more rapid than in any of the atmospheric exposures.

Chromate film on aluminum was found to be very effective in providing protection for aluminum in tropic marine, open-field, and rain-forest environments. Water- and dichromate-sealed anodized aluminum were also found to perform satisfactorily under tropical regions except in a marine environment; a water-sealed aluminum specimen corroded slightly after two years of exposure to a marine environment.

Construction

Precautions must be taken to prevent interaction between aluminum and other building materials. Fittings for aluminum components should ideally always be made of aluminum or an aluminum alloy to avoid galvanic corrosion. The nonmagnetic stainless steels are generally compatible with aluminum, but the contact may not be desirable in marine or severe industrial environments. Direct contact between aluminum and steel should be avoided. Insulating washers may be used to isolate the metals. The most hazardous form of bimetallic corrosion of aluminum occurs as a result of interaction with copper. The runoff from copper roofs or water discharged through copper pipes should not be allowed to wash over or splash against aluminum. The contact between aluminum and most of the concretes, mortars, and plasters is generally satisfactory.

[57] F. Pearlstein and L. Teitell, *Corrosion of Aluminum in the Tropics*, Report FA-A67-28/AD684520 (Department of the Army, 1967).

Nevertheless, for more satisfactory service it is recommended that the contact surface of the aluminum be coated with a synthetic or rubber-base sealant meeting specification TT-S-230 or TT-S-00227 and that the masonry or concrete surface be protected with roofing felt.

The design should also effectively eliminate the risk of condensation occurring under aluminum roofing and behind wall cladding.

Plastics

Materials

The plastics offer many advantages over other materials. In general, they provide good resistance to water, corrosion, and weathering, making them suitable for such uses as facades, gutters, pipes, bathroom fixtures, and waterproofing. Other virtues of plastics, such as low thermal conductivity and ease of maintenance, make them particularly suitable as building materials in the tropics. Nevertheless, care must be exercised to make sure that the material selected is the most suitable for a particular application since the range of available plastics is very wide and not all materials possess all of the virtues.

The plastics fall into two major classifications; thermoplastics and thermosetting materials. Thermoplastics are made up of thread-like molecules which soften when heated and resolidify upon cooling. Thermosetting resins are made up of cross-linked thread-like molecules which harden when heated. Thermoplastics lack the heat resistance, creep resistance, and chemical resistance of the thermosetting types. Thus, the thermosetting resins are generally preferred for structural applications.

The distinction between thermoplastic and thermosetting materials was once clearly defined but is becoming increasingly blurred. Many of the thermoplastics are now being cross-linked for special purposes—for instance, in acrylics for glazing, PVC plastisols for structural adhesives, and polyethylenes for high-temperature pipe. Some of the resins which are cross-linked are also available in thermoplastic form—for instance, the phenoxies and some of the polyurethanes. In view of these variations, it is essential that the architect or designer obtain physical property data from manufacturers to characterize the grades of materials selected for a given application.

The selection of plastics for interior applications is, in general, not as critical as for exterior applications. For quick reference, the physical properties of several plastics previously used for exterior applications are presented below:

Polyvinyl chloride (PVC). Rigid PVC can be stabilized to weathering, has good water, solvent, and chemical resistance, and is self-extinguishing. However, it degrades in high-temperature service. Translucent grades may be sensitive to ultraviolet light. PVC is used for siding, rain gutters and downspouts, window frames, roof lights, and building panels.

Acrylonitrile butadiene styrene (ABS). ABS plastic is tough and rigid. It has a good balance of heat resistance, dimensional stability, chemical resistance, and electrical properties. ABS is used for door and window components, drain, waste, and vent piping, weather seals, concrete forms, and appliance housings.

Glass-fiber-reinforced polyester resin (GRP). Glass-fiber-reinforced polyester resin offers high strength, good electrical properties, and good water, solvent, and chemical resistance. Its outdoor weathering is not outstanding. It can be improved, however, by coating the surface with polyvinyl flouride (PVF) or acrylates. A study indicates that panels coated with PVF film would require no maintenance for fifteen years. GRP is used for cladding, roof lights, and window frames.

Acrylic sheet. Acrylics provide outstanding transparency, colorability, and excellent outdoor weathering characteristics. Scratch resistance and impact resistance are not outstanding, however. Acrylics are used in glazing, skylights, cladding, building panels, and decorative items.

Construction

Some plastics are susceptible to termite attack. Therefore, they must not be used for underground construction unless otherwise proved by the manufacturers. Although weathering action is not critical, tropical and especially hot desert conditions cause definite deterioration, particularly in thermoplastic materials which may warp and crack. Care must be taken to select materials that possess high dimensional stability and/or to provide proper design details to alleviate or reduce the effect of high temperature.

Masonry

General

Masonry is satisfactory for general construction in both desert and tropic regions. Blocks should be well vibrated to reduce porosity and, when possible, auto-

clave cured to reduce shrinkage. TM-809-3, Masonry Structural Design for Buildings, should be followed for design.

Upon delivery to the site, blocks must be stored on planks or other supports to protect them from direct contact with soil. Masonry blocks in tropic regions should be stored under canvas, plastic tarps, or waterproof paper so that the block units are not saturated with water when they are laid. On the other hand, masonry blocks in desert regions may become too dry because of the solar heat unless they are wetted down periodically. Lack of moisture in the block and in the mortar will reduce the quality of the bond. To minimize this problem, it is recommended that in addition to wetting down the blocks the mortar should be mixed only when needed. Also, a little extra water should be used in the mortar mix, and shorter bed joints should be used while laying the blocks.

Embedded Steel

General

Steel embedded in concrete for such purposes as exterior railings, hand rails, fences, guard rails, and anchor bolts should be galvanized. The entire embedded length should be coated with asphalt to at least 1 in. (2.5 cm) above the concrete surface.

Fasteners

General

Wood Fasteners. Plain steel fasteners such as nails, bolts, screws, and braces corrode rapidly and promote wood decay. In addition, the rust from fasteners will leave unsightly stains on wood surfaces. Therefore, plain steel fasteners should not be used in the tropic region. Galvanized steel lasts considerably longer than plain fasteners but is subject to corrosion at points where the coating fractures. Cement-coated nails and tempered aluminum nails have given good service. High-nickel stainless steels are excellent but are too costly for general use.

Metal Fasteners. Fasteners for metal must be insulated if dissimilar metals are used. When attaching roofing sheets to basic structures, welds should not be used because of the difficulty in clearing, coating, and protecting welded areas.

Adhesives

General

An epoxy-resin adhesive meeting the requirements of MIL-A-8623 can be used for structural bonding metal, plastic laminates, wood, and glass to each other and in combination. Pressure-sensitive tape meeting the requirements of MIL-T-23142 can be used as a separator for the prevention of galvanic attack between dissimilar metals. Special care must be taken in selecting the right kind of adhesives for joining metals since corrosion may be caused by certain adhesives. For instance, copper is subject to undesirable corrosion when joined with a one-part silicone adhesive or with epoxy processed with curing agents containing amine. To repair concrete, an epoxy binder meeting the requirements of MMM-B-350 may be used.

6 CONCLUSIONS AND RECOMMENDATIONS

Conclusions

In field observations and surveys conducted at military installations during this investigation, a considerable number of buildings were found to be performing unsatisfactorily. Most faults resulted primarily from poor planning, improper usage of materials, or inadequate attention to design and construction details. Most of the problems could have been avoided or their adverse effects reduced if a set of criteria or guidelines had been available to the designers. It is intended that the guidelines developed in this study should fill this need. However, the guidelines presented here are by no means complete; conclusive guidelines have not yet been developed for several items because of a lack of data. In addition, it should be stressed that periodical review and updating are required to maintain the usefulness of the guidelines.

Recommendations

1. It is recommended that the guidelines developed be adopted by the Army for use in designing facilities in desert and tropic regions.

2. It is recommended that to increase the usefulness of the guidelines the collection and analysis of data be continued in the following areas:

a. Durability of pressure-treated wood for long-term usage (permanent construction) in the tropics

b. Durability of plastics in both desert and tropic regions

c. Effectiveness of different types of roof construction in the tropics

d. Durability of different roof-flashing details in tropics

e. Effectiveness of insulated lightweight walls versus heavy walls in desert climates

f. Effectiveness of the natural ventilation provided by a pitched roof in hot-dry climates

g. Effects of dust and heat on the durability of common building hardware

APPENDIX A: TERMITE CONTROL BY SOIL POISONING*

Slab-on-ground Foundations

Apply 4 gal. (15.1 ℓ) of chemical per 10 linear ft (3.0 m) to the soil in critical areas under the slab, such as along the inside of foundation walls, along both sides of interior partition foundation walls, and around plumbing.

Apply 1 gal. (3.8 ℓ) of chemical per 10 ft^2 (0.9 m^2) as an overall treatment under the slab and attached slab porches and terraces where the fill used is soil or unwashed gravel.

Apply 1½ gal. (5.7 ℓ) of chemical per 10 ft^2 (0.9 m^2) to those areas where the fill is washed gravel or other coarse absorbent material, such as cinders.

Apply 4 gal. (15.1 ℓ) of chemical per 10 linear ft (3.0 m) of trench along the outside edge of the building after all grading is finished.

Perimeter Foundation

Apply 4 gal. (15.1 ℓ) of chemical per 10 linear ft (3.0 m) of trench along the inside of foundation walls, along both sides of interior partitions, and around piers and plumbing. Do not apply an overall treatment in crawl spaces.

Apply 4 gal. (15.1 ℓ) per 10 linear ft (3.0 m) of trench for each foot of depth from grade to footing along the outside of foundation walls, including the part beneath entrance platforms, porches, etc.

Apply 4 gal. (15.1 ℓ) per 10 linear ft (3.0 m) along the inside and outside of foundation walls of porches.

Apply 1 gal. (3.8 ℓ) per 10 ft^2 (0.9 m^2) of soil surface as an overall treatment under attached concrete platforms and porches that are on fill or ground.

Voids in masonry foundations: Treat all voids in masonry foundations with at least 2 gal. (7.6 ℓ) of chemical per 10 linear ft (3.0 m) of wall at or near the footing.

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*This material on application rates was taken from H. R. Johnston, *Subterranean Termites, Their Prevention and Control in Buildings*, Home and Garden Bulletin No. 64 (USDA, 1972), pp 22-23.

APPENDIX B:
PRESSURE-TREATED WOOD PROPERTIES

Table B1
Preservatives and Properties of Pressure-Treated Wood*

Preservative	Color	Odor of Treated Wood	Paintability of Treated Wood
Creosote	dark brown to black	strong aromatic	no
Pentachlorophenol	almost colorless to dark brown (solvent color)	same as odor of solvent	depends of type of solvent
Water Soluble			
Acid Copper Chromate (ACC)	yellowish-green	slight	yes, if wood is dry
Ammoniacal Copper Arsenite (ACA)	yellowish-green	slight	yes, if wood is dry
Chromated Copper Arsenate (CCA) (Types A, B and C)	brownish-green	slight	yes, if wood is dry
Chromated Zinc Chloride (CZC)	brownish-green	slight	yes, if wood is dry
Fluor Chrome Arsenate Phenol (FCAP)	yellowish-brown	slight	yes, if wood is dry

*From D. H. Percival and C. S. Walters, *Pressure Treated Wood*, Circular D73 (Small Homes Council–Building Research Council, University of Illinois, 1975), pp 3, 8.

Table B2
Recommended Preservative Treatments*

Product	Use Location	Creosote	Penta	ACC	ACA	CCA	CZC	FCAP	AWPA Specification
		Preservatives							
Lumber	above ground								C2
Lumber	in soil or concrete						NR	NR	C2
Building poles	soil contact						NR	NR	C23
Sawn posts	soil contact						NR	NR	C16
Plywood	soil, concrete or water contact						NR	NR	C9
Millwork	no soil contact	NR							C16
All weather wood foundation material	soil contact	NR	NR	NR			NR	NR	C2, C9[1]

[1] Minimum retention for both lumber and plywood is 0.60 pounds per cubic foot

NR = not recommended

*These charts were taken from D. H. Percival and C. S. Walters, *Pressure Treated Wood*, Circular D73 (Small Homes Council–Building Research Council, University of Illinois, 1975), pp 3, 8.

APPENDIX C:
TROPICAL TIMBER VARIETIES

Table C1
Tropical Timber Varieties

*Note: The species listed below are given to provide the reader with several local species of suitable woods for construction in tropical areas. Native North American species were left out because the purpose was to list the lesser known trees of South and Central America, Africa, Asia, and Austraila.**

Species and other names	Botanical name	Distribution	Characteristics	Uses
Agathis	Agathis Alba	South-East Fiji Islands, New Zealand	large, almost cylindrical trees, straw coloured to brownish, easily worked, little distortion	Interior and exterior work, plywood
Abura	Mitragyna Stipulosa	Equatorial West Africa	pale, reddish brown, moderately soft, medium strength, holds nails and screws well, acid resistant	Floors, chemical laboratory fittings
Afrormosia	Afrormosia Elata	Gold Coast Cameroon, Congo	brownish hardwood with dark streaks, heavy, hard, strong, slightly spiral grained, little distortion, easily worked	Bridge, harbor and dock-building, external cladding, floors
Agba	Gossweilerodendron Balsamiferum	Angola, Gold Coast, Nigeria Belgian Congo	also called Tola Branca, yellowish pink to brown, moderately hard, fairly strong, straight grained, easily worked	Interior, exterior work, floors, facade cladding
Amarant	Poltogyne Paniculata	Surinam, Brazil Trinidad Guayana	violet blue (treat to retain color), strong, heavy, hard, easily worked, difficult to nail, almost no distortion	Cladding, parquet and dock construction in water and ship-building, framed structures
Andira	Andira Coriacea	Guayana, Surinam Brazil	brick to dark red with paler streaks and patches, hard, strong, tough, spiral grain, easily worked	Interior and exterior work, furniture, shipbuilding, plywood

*The information in this table was taken from G. Lippsmeier, *Building in the Tropics* (Verlag Georg D. W. Callwey, 1969), pp 123-129.

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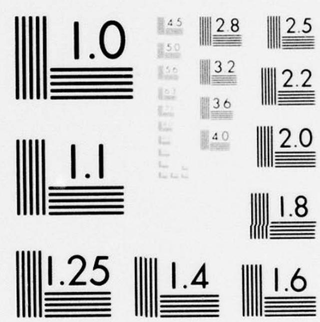

MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS-1963-A

Table C1 (cont'd)
Tropical Timber Varieties

Species and other names	Botanical name	Distribution	Characteristics	Uses
Alerce	Fitzroya Cupressoides	Chile, Patagonia	large diam, slow growing, straw colored to brownish, little distortion, easily worked	Interior and exterior work
Azobe (Bongossi)	Lophira Procera	Equatorial W. Africa	Chocolate coloured, heavy, hard, very strong, coarse grained, difficult to work, little distortion	building, civil engineering, construction in water, industrial flooring, bridge planking
Bangkirai	Shorea Laeifolia	Bornea	pale yellowish to reddish brown, heavy, hard, fine structure, easily worked, high resistance to abrasion, greater strength than teak or oak	construction in water, heavy structural work, industrial flooring
Basralocus	Dicorynia Parensis	Surinam Guayana	chocolate to grey brown, heavy, hard, high strength, coarse spiral grained, easily worked	construction in water, wooden paving
Bilinga (Opepe)	Sarcocephalus	Equatorial West Africa	gold to orange, yellow, fine spiral grained, strong, fairly hard, easily worked	All sorts of timber building construction, interior and exterior
Bosse (Nigerian)	Guarea Cedrata	Equatorial West Africa	pale brown, finely grained, strong, easily worked	panelling, parquet flooring
Courbaril	Hymenaea Courbaril	Tropical South America	red to dark red-brown, hard, dense, strong, fine grained, easily worked	Interior and exterior cladding for facades, floors
Dabema	Piptadenia Africana	Equatorial West Africa & East Africa	grey green to yellow brown, moderately strong and hard, coarse grained, tends to distort, easily worked	door and window construction, floors

Table C1 (cont'd)
Tropical Timber Varieties

Species and other names	Botanical name	Distribution	Characteristics	Uses
Danta	Nesogordonia papaverifera	Equatorial West Africa	red to mahogony brown, moderate fine spiral grained, hard, good workability	Floor, veneers
Doussie (Afzelia, Apa)	Afze Africana	Equatorial West Africa	pale brown, heavy, hard, coarse grained, easily worked (similar to oak), resistant to weak acids	Structural timber for housing panelling, parquet and strip flooring
Framire (Black Afara)	Terminalia Ivorensis	Equatorial West Africa	related to Limba, pale yellow to pale brown, soft, moderately light, coarse grained	panelling, floors
Imbuia (Brazilian walnut)	*Phoebe* Porosa	*Southern* Brazil	*olive to chocolate* brown, similar to walnut, good for large units, hard, heavy, fine grained	panelling, parquet flooring, veneers
Iroko (Kambala)	Chlorophora Excels	Equatorial East and West Africa	gold brown, attractive graining, very easily worked, similar to oak	Interior and exterior work, panelling, floors
Jarrah	Eucalyptus Marginata	Western Australia	red brown, hard, dense, very tough, high resistance to wear	specially for parquet and strip flooring
Kapur (Camphor wood)	Dryobalanops Aromatica	Borneo Sumatra Moluccas	Pale brown to pinkish red, moderately fine grained, easily worked	Interior and exterior work, cladding for facades, floors
Karri	Eucalyptus Diversicolor	Australia	pale red, similar to Jarrah, heavy, hard, tough, difficult to work	Bridge building, construction in water
Louro (Louro Vermelho)	Ocotea Rubra	Surinam Guayana, Brazil	brown red to orange brown, coarse grained, moderately dense, moderately strong, easily worked	exterior cladding, wall and ceiling panelling, plywood, veneers

Table C1 (cont'd)
Tropical Timber Varieties

Species and other names	Botanical name	Distribution	Characteristics	Uses
Manbarklak (Kokoralli)	Eschwei-lera Longipes	North east South America, Surinam	grey brown, very hard, strong, tough, very heavy, straight grained, high silica content, cannot be machined	exclusively sea or harbor building, highly resistant to attack of marine borers due to high silica content
Mansonia (Nigerian walnut)	Mansonia Altissima	West Africa Cameron to Ivory Coast	olive to violet brown, similar to American walnut	Interior and exterior work, floors, veneers
Matakki (Manil,)	Symphonia globulifera	Tropical South America	yellowish brown, fairly hard, moderately heavy, coarse spiral grained, easily worked	Frame con-structions, windows, floors
Merbau (lpi)	Intsia Bakeri	Indonesia north west Guinea, South East Asia	variable from brown grey to dark brown, coarse grained, hard, easily worked, similar to Afzelia	building construction, industrial floors
Mora (Peto, Pracuuba)	Mora Excelso	Tropical America	red brown to grey brown, very strong, very heavy, very hard, spiral grain, moderately easy to work	structural timber, floors, construction in water
Niangon (Nyankom, Wismore)	Tarrietia utilis	Ivory Coast	pale red brown to pinkish, coarse, grained, spiral grain, easily worked	windows, facade cladding, shuttering
Niove (Kamashi, Sunzu, Wanga)	Staudtia Gabonensis, St. Kameru-nensis	Portuguese West Africa, Congo, Cameroon, Gabun	red brown to yellow brown, dark streaks, fine grained, hard, heavy but brittle, worked easily	window frames, facade cladding, floors
Padouk (African P. Andaman P. Indian P.)	Pterocarpus, Soyanxii, various species of P.	Equatorial West Africa, Andaman, Burma, Indonesia, Philippines	grey white to yellow white, hard wood, blood red to dark brown, moderately hard, strong, dense, fairly tough, coarse, spiral grained	shuttering, exterior cladding, floors

Table C1 (cont'd)
Tropical Timber Varieties

Species and other names	Botanical name	Distribution	Characteristics	Uses
Peroba de Campos (Peroba Amarella)	Paratecoma Peroba	Brazil	pink beige to yellow red (similar to teak) darkening later, moderately heavy, dense, tough, easily worked, air cracks	for all types of construction, windows, doors, floors
Peroba Rosa (Red Peroba, Palo Rosa, Amarello)	Aspidosperma peroba	Brazil	orange to salmon colored with dark streaks, moderately hard and heavy, dense, tough, sometimes spiral grain, easily worked	Interior and exterior work, floors
Pitch Pine (Longleaf Pine, Slash Pine)	Pinus Palustris, Pinus Caribaea	Central America, Southern U.S.A.	Species of pine with slight differences, yellow white, very strong, easily worked, especially for heavy structural work	Interior and exterior work, floors, staircases, panelling, bridge and shipbuilding
Ramin (almin)	Gonystylus bancanus	Malaya, Borneo	yellowish white, even grained (similar to Limba), good worked but crack formation	interior work, plywood, doors
Salie (Encens rouge, Gommier de Montagne)	Tetragastris host-manni, various species of T.	Guayana, Surinam, Central America	orange, yellow to dark brown, strong, dense, tough, fine straight grained, easily worked	Panelling, windows, furniture, parquet and strip flooring
Schitola (Red Tola)	Oxystigma Oxyphyllum	Equatorial West Africa	pale red brown, dark streaks, straight, spiral grained, moderately strong, often mottled, easily worked	Carpentry, plywood, veneers
Sucupira (Angelim, Arbre a Chou)	Bowdichia various species, Diplotropis various sp.	Surinam, Guayana, Brazil, Venezuela	dark brown to blackish, hard, dense, strong, spiral grain, worked easily	Interior and exterior work

Table C1 (cont'd)
Tropical Timber Varieties

Species and other names	Botanical name	Distribution	Characteristics	Uses
Tasua (Thitni)	Amoora various sp.	Burma Siam	similar to Chumprak, dense, strong, moderately hard, fairly fine grained, somewhat oily, easily worked	Interior and exterior work, structural timbers
Teak	Tectonia Grandis	Java, Madoera, Moena, Siam, Burma Indochina, India	Regional differences, greatest difference Siam/Burma teak and Java teak (heavier and harder), best wood in the world	Suitable for all purposes

APPENDIX D: SUPPLEMENTAL CRITERIA FOR AIR-CONDITIONING SYSTEM DESIGN IN TROPICAL ENVIRONMENTS

The provisions contained in this section apply to comfort cooling systems used in tropical environments. Tropical environments occur in geographical areas in which mean annual temperatures are higher than 70°F (21°C). These instructions supplement requirements contained in Department of Defense Construction Criteria Manual D.O.D. 4270.1M and Department of the Army Technical Manual TM 5-810-1, *Mechanical Design Heating, Ventilating and Air Conditioning.*

Design Temperatures

1. The inside design temperature shall conform to the requirements of D.O.D. Manual 4270.1M.

2. Outside design temperatures shall be based on the 2½% dry-bulb and 5% wet-bulb temperatures for geographical site locations tabulated in Technical Manual TM 5-785, *Engineering Weather Data.*

Design Requirements

Heat-gain calculations shall be based on procedures contained in the current edition of the ASHRAE *Handbook of Fundamentals.* Peak and partial load calculations shall be prepared. To insure that the equipment selected will provide maximum refrigeration-system operating time, the equipment shall be sized to provide a 3°F (1.7°C) rise above inside design temperature under peak load. During normal loads the space temperature will remain constant or near the space-temperature control set point. Reduction in peak room sensible heat load, to allow for the 3°F (1.7°C) temperature rise, can be calculated using the method outlined in the *Carrier System Design Manual for Load Estimating.*

Outside Air Requirements

1. Outside air intake requirements shall be based on minimum values recommended by the ASHRAE *Handbook of Fundamentals.* Outside air intake should be reduced to an absolute minimum in all facilities during unoccupied periods.

2. "Outside air dampers should close automatically when compressor cycles off on those systems where the fan coil unit is not automatically cycled off with the compressor."

Exhaust Air Requirements

A maximum of 80% of the outside air supply should be exhausted to maintain a positive pressure level within the air-conditioned area and thus reduce infiltration. Building exhaust air should be used for ventilation of mechanical equipment areas to reduce condensation on cold equipment.

Sheet-Metal Ductwork

Ducts exposed to the exterior environment shall be constructed of aluminum sheets conforming to Military Specification MIL-A-52174. This requirement includes the outside air intake and mixed air ducts leading to the air-handling units. Galvanized-steel or aluminum ductwork is optional for conditioned air supply inside buildings.

Diffusers, Registers, and Grills

These items shall be constructed entirely of aluminum to prevent surface deterioration caused by condensation.

Insulation Requirements

1. The insulation thickness shall be adequate to insure that surface condensation is minimized. The ASHRAE *Handbook of Fundamentals* provides guidance in the selection of insulation thickness at design operating and ambient temperatures.

2. Factory-insulated equipment is not generally available with sufficient insulation thickness to prevent surface condensation in tropical environments. If practicable, air-handling units and cold equipment should be located in conditioned areas. The additional costs incurred in conditioning these areas will be offset by lower maintenance costs and extended equipment life. A requirement for additional insulation should be investigated if it is not possible to locate cold equipment in conditioned areas.

Space Temperature Controls

1. Small systems which utilize compressor cycling for temperature control should also cycle the evaporator fan to maintain a lower relative humidity level in the air-conditioned space.

2. Cooling-coil face and bypass dampers should be provided for comfort cooling applications to maintain a lower relative humidity level under reduced load conditions. Returned air only should be bypassed if possible. The chilled water coil control valves should not be modulated as high relative humidity conditions will occur during reduced-load periods.

Ferrous Metal Protective Finish

All equipment and items located outside of buildings shall have weather resistant finishes that will withstand 500 hours of exposure to the test conditions specified in Method 6071 of Federal Standard 141. This requirement is also applicable to cold equipment located inside buildings except for equipment located in air-conditioned spaces.

Piping Systems

Maximum use should be made of materials or finishes which are inherently corrosion resistant and are most cost effective. Dissimilar metals shall be separated by dielectric isolators. Interior and exterior uninsulated ferrous metal surfaces shall be protected in accordance with the requirements of OCE Guide Specification CE-250, Painting, General.

Energy Conservation

Consideration shall be given to achieving operating economies by precooling outside makeup air with air-to-air rotary heat exchangers or runaround systems using water coils whenever the exhaust air rate is 4000 CFM or greater. The use of charcoal filtration for air recovery will be considered where economically feasible.

Specifications

The requirements of OCE Guide Specifications CE301.35, CE301.36, and CE301.37 will be used to the maximum extent except for special protective metal finishes and insulation thicknesses. Optional materials shall be selected based on information obtained from the experience of the using agency.

Refrigerant, Chilled Water, and Condensate Pipe Insulation

"In general, fiberglass insulation has not been successful in wet tropical areas. Foam glass, expanded plastic, and polyurethane are the preferred materials. The objection to fiberglass insulation stems from frequent and untimely failure of vapor barrier materials and of tapes and adhesives employed in sealing the joints. Such failures permit the insulation to become quickly saturated, unsightly and useless."

APPENDIX E:
PAINT AND COATING SYSTEM RECOMMENDATIONS

Table E1
Tropical Paint Systems*

Exterior Substrate	Substrate Condition	Surface Preparation	Finish	Primer	Top Coat	Remarks
Concrete and	New	See TS-09910	Flat	TT-P-19	TT-P-19	For porous blocks, use TT-P-19 filler formula for primer.
Masonry	Painted	See TS-09910	Flat	TT-P-55	TT-P-19	Use as a filler on masonry block if
	New		Flat	TT-P-21	TT-P-21	painting not required.
Wood	New	See TS-09910	Flat	TT-P-25	TT-P-19	For white and light colors.
	New	See TS-09910	Gloss	TT-P-25	TT-P-37	For deep colors only.
	New	See TS-09910	Gloss	TT-P-25	TT-P-81	For medium shades.
	Painted			TT-P-620	–	Top coat as applicable.
	Doors & Frames	See TS-00910	Gloss	TT-P-25	TT-E-489	Primer and two coats minimum.
Ferrous	Galvanized	MIL-C-15328	Gloss	TT-P-641	TT-E-489	Applicable for chain-link fence.
	New	See TS-09910	Gloss	TT-P-645	TT-E-489	Flat is not recommended for exterior.
	Asphalt coated		Aluminum	TT-P-38	TT-P-38	Sealer/primer for top coat.
Aluminum	New	Pretreatment MIL-P-14504	Gloss	TT-P-645	TT-E-489	
Copper	New	Pretreatment MIL-P-14504	Gloss	TT-P-645	TT-E-489	

*From *Materials and Design Criteria for Construction in Tropical Environments*, NAVFAC, Draft Report (Department of the Navy, 1977), pp 09910-6.

Table E2
Desert Paint Systems, Exterior and Interior*

Surface	Surface preparation and pretreatment	First coat	Second coat	Third coat
Exterior stucco surfaces	Remove foreign matter, efflorescence and loose particles; roughen glazed surfaces.	Exterior emulsion paint.	Exterior emulsion paint.	None.
Exterior concrete masonry units	Remove foreign matter, loose particles, and efflorescence. Dampen as specified	Cement-emulsion filler.	Exterior emulsion paint.	None.
		or		
		Cement-emulsion filler.	Cementitious paint for limited use as previously specified.	
Exterior concrete indicated to be painted.	Remove foreign matter.	Exterior emulsion paint.	Exterior emulsion paint.	None.
Exterior ferrous surfaces, exposed, unless otherwise specified.	As previously specified	Exterior oil paint.	Exterior oil paint.	None.
Interior walls and ceilings in food-serving and laundry areas, except ferrous surfaces and concrete masonry units, unless otherwise specified.	As previously specified for each type of surface.	TT-P-29 or TT-S-179 or TT-P-650, type I. (TT-S-179 is not permitted on gypsum wallboard.)	TT-E-543 or TT-E-545.	TT-E-505 or TT-E-506.
Interior exposed ferrous surfaces, unless otherwise specified.	As previously specified	TT-E-543 or TT-E-545.	TT-E-508 or TT-E-509	None.
Ferrous surfaces of mechanical and electrical equipment that has been factory primed.	Solvent clean as specified.	TT-E-489, class A.	TT-E-489, class A.	None.
Ferrous surfaces of mechanical and electrical equipment that has been factory finished.	Clean as required.	None.	None.	None.

*From *Specification for E. M. Barracks Addition – Yuma Proving Grounds*, Specification No. 4594 SPL (Department of the Army, 1973), pp 9F14-17.

Table E2 (cont'd)
Desert Paint Systems, Exterior and Interior*

Surface	Surface preparation and pretreatment	First coat	Second coat	Third coat
Wood and metal interior trim and doors, except in food-serving and laundry areas.	As previously specified for each type of surface.	TT-E-543 or TT-E-545.	TT-E-508 or TT-E-509.	None.
Interior wood and metal surfaces in food-serving and laundry areas, other than equipment and machinery.	As previously specified for each type of surface.	TT-E-543 or TT-E-545.	TT-E-505 or TT-E-506.	None.
Interior galvanized surfaces, unless otherwise specified.	As previously specified.	Same as for adjacent surfaces.		
Interior wood surfaces unless otherwise specified.	Remove foreign matter. Sandpaper as required.	TT-E-543 or TT-E-545.	TT-E-508 or TT-E-509.	None.
Electrical conduit runs, metallic tubing, uninsulated ducts and pipes, pipe hangers, louvers, grilles, and air outlets in areas having painted adjacent surfaces.	As previously specified for each type of surface.	TT-E-543 or TT-E-545.	TT-E-508 or TT-E-509.	None.
Exposed-to-view cotton or canvas fabric covering over insulation on pipes, tanks, and other equipment, interior.	As previously specified.	TT-P-30.	TT-P-30 or TT-P-29.	None.
Exposed-to-view paper facing of vapor barrier jackets over pipe or duct insulation.	As previously specified.	Two coats of paint to match adjacent areas.		
Exposed-to-view presized or adhesive finished glass cloth over insulation on pipes, ducts, and equipment, interior.	Remove foreign matter.	TT-P-30.	TT-P-30.	None.
Exterior galvanized surfaces.	As previously specified.	TT-P-641, type II, or MIL-P-26915, type I, class A.	Exterior oil paint.	None.
Exterior aluminum and aluminum-alloy surfaces.	As previously specified.	TT-P-645.	TT-E-489, class A.	None.

Table E2 (cont'd)
Desert Paint Systems, Exterior and Interior*

Surface	Surface preparation and pretreatment	First coat	Second coat	Third coat
Exterior caulking compound.	As specified in section: *Caulking and Sealing.*	*Aluminum* paint.	*Same as adjacent areas.*	
Interior concrete masonry units, concrete except concrete floors and textured ceilings, gypsum board, unless otherwise specified.	As previously specified for each type of surface.	TT-P-29.	TT-E-543 or TT-E-545.	TT-E-508 or TT-E-509.
Interior plaster, unless otherwise specified.	As previously specified.	TT-S-179 or TT-P-29.	TT-E-543 or TT-E-545.	TT-E-508 or TT-E-509.
Interior concrete masonry-unit walls in food-serving and laundry areas, unless otherwise specified.	As previously specified.	Cement-emulsion filler.	TT-P-29 or TT-S-179.	TT-E-543 or TT-E-545. or *Fourth coat* TT-E-505 or TT-E-506.

CITED REFERENCES

All-Weather Home Building Manual (NAHB Research Foundation, Inc., November 1975), p 129.

ARMM Consultants, Inc., *Moisture Problems in Building*, Contract N 6 2467-76-C-0696 (Department of the Navy, 1976).

Army Facilities Components System, TM5-301 Series (Department of the Army, 1970).

Army Facilities Components System–Planning, TM5-301 (Department of the Army, 1973).

Army Facilities Components System–Designs, TM5-302 (Department of the Army, 1973).

Army Facilities Components System–Logistic Data and Bills of Material, TM5-303 (Department of the Army, 1973).

Danby, M., "The Design of Buildings in Hot-Dry Climates and the Internal Environment," *Build International*, Vol 6, No. 1 (1973), pp 61, 63, 65.

Eaton, K. J. and J. B. Menzies, *Roofs, Roofing and the Wind*, Bulletin CP75 74 (Building Research Station, Garston, Watford, England, 1974), p 3.

Givoni, B., "Buildings for Hot Climates," *Building Research and Practice*, Vol 2, No. 6 (1975).

Givoni, B. and M. E. Hoffman, "Effect of Roof Design on the Indoor Climate in Hot Arid Zones," *Build International*, Vol 6, No. 5 (1973), pp 531, 535.

Guide Specification for Military and Civil Works Construction–Painting, General, CE 250 (Department of the Army, 1968), pp 12, 22.

Howdyshell, P., *The Use of Coral as an Aggregate for Portland Cement Concrete Structures*, Technical Report M-88/AD#784092 (U.S. Army Construction Engineering Research Laboratory, June 1974).

Johnson, S. M., and T. C. Kavanagh, *The Design of Foundations for Buildings* (McGraw-Hill, 1968), p 60.

Johnston, H. R., et al., *Subterranean Termites, Their Prevention and Control in Buildings*, Home and Garden Bulletin No. 64 (U.S. Department of Agriculture, 1972), pp 22-23, 25.

Kelly, K., and R. T. Schnadelbach, *Landscaping the Saudi Arabian Desert* (Delancey Press, 1976), pp 30, 49.

Koenigsberger, O. H., et al., *Manual of Tropical Housing and Building, Part One: Climatic Design* (Longman, 1973), pp 124, 126.

LeMessurier Associates/SCI, *Investigations of Cracking in Structures, King Abdul-Aziz Military Cantonment* (unpublished, 1974), pp 122, 130.

Lippsmeier, G., *Building in the Tropics* (Verlag Georg D. W. Callwey, 1969), pp 123-129, 162, 165, 178, 179.

Material and Design Criteria for Construction in Tropical Environments, NAVFAC Draft Report (Department of the Navy, 1977), pp 07500-1; 15401-1; 09910-1, 2, 3, 4, 6.

Materials Criteria for Construction in Tropical Environments, NAVFAC INST 11012.98A (Department of the Navy, 1967), pp 20, 22, 23, 25, 44.

Moore, R. J., and L. G. Spielvogel, *Trip to Naval Facilities in Guam and the Philippines* (trip report, October 1976).

NAHB Research Foundation Inc., *All Weather Home Building Manual* (U.S. Government Printing Office, 1975), pp 97, 104, 107.

Pearlstein, F., and L. Teitell, *Corrosion of Aluminum in the Tropics*, Report FA-A67-28/AD684520 (Department of the Army, 1967).

Percival, D. H., and C. S. Walters, *Pressure Treated Wood*, Circular D73 (Small Homes Council–Building Research Council, University of Illinois, 1975), pp 3, 8.

Playnter, J., "Evaporative Cooling–the Principles Involved and Their Application to Building in Western New South Wales," *Architectural Science Review*, Vol 7, No. 3 (1964), p 110.

Ramsey, C. G., and H. R. Sleeper, *Architectural Graphic Standards* (John Wiley and Sons, 1970), p 320.

Reps, W. F., and E. Simon, *Design, Siting, and Construction of Low-Cost Housing and Community Buildings to Better Withstand Earthquakes and Windstorms*, Building Science Series 48 (National Bureau of Standards, 1974).

Saini, B. S., *Architecture in Tropical Australia* (Melbourne University Press, 1970), pp 29, 35, 79.

Specifications for Construction of 48 U.S. Quarters at Various Locations in the Canal Zone, Serial No. PC-74-45 (Panama Canal Company, April 1974), p 15-2.

Specification for E.M. Barracks Addition–Yuma Proving Ground, Specification No. 4595 SPL (Department of the Army, 1973), pp 9F14-17.

Weston, E. T., *Ventilation and Cooling of a House with an Attic Exhaust Fan*, Special Report #9 (Commonwealth Experimental Building Stations, Sydney, Australia, 1972).

Whiteley, P., *Recommendations for Painting in Tropical Climates*, Tropical Building Studies No. 4 (Building Research Station, Garston, England, 1962), p 19.

Zeevaert, L., *Foundation Engineering for Difficult Subsoil Conditions* (Van Nostrand Reinhold Co., 1972), pp 15, 16.

UNCITED REFERENCES

Building Construction, BRE Digests (London: MTP Construction, Medical and Technical Publishing Company Ltd, 1973).

Design Criteria for Facilities in Areas Subject to Typhoons and Hurricanes, TM 5-809-11 (Department of the Army, 1973).

Egan, M. D., *Concepts in Thermal Comfort* (Prentice-Hall, Inc., 1975).

Foyle, A. M., ed., *Conference on Tropical Architecture* (London: George Allen and Unwin Ltd, 1953).

Fry, M., and J. Drew, *Tropical Architecture in the Humid Zone* (London: B. T. Batsford Ltd, 1956).

Givoni, B., *Man, Climate and Architecture* (Elsevier Publishing Co., 1969).

Johnson, S. M., *Deterioration, Maintenance, and Repair of Structures* (McGraw-Hill Book Company, 1965).

Lee, D. H. K., *Physiological Objectives in Hot Weather Housing* (United States Housing and Home Finance Agency, 1953).

Lessons Learned - Military Engineering, DA PAM 525-3 (Department of the Army, 1967).

Marshall, R. D., *Engineering Aspects of Cyclone Tracy, Darwin, Australia*, NGS Building Science Series 86 (National Bureau of Standards, 1976).

Masonry Structural Design for Buildings, TM 5-809-3 Series (Department of the Army).

Peck, R. B., W. E. Hanson, and T. H. Thornburn, *Foundation Engineering* (John Wiley and Sons, 1974).

Simpson, J. W., and P. H. Hornobin, *The Weathering and Performance of Building Materials* (John Wiley and Sons, 1970).

Skeist, I., *Plastics in Building* (Reinhold Publishing Corp., 1966).

Southwell, et al., *Natural Resistance of Woods to Biological Deterioration in Tropical Environments, Part I, Screening Tests of a Large Number of Wood Species*, NRL-5673 (Naval Research Lab, 1962).

Walker, G. R., J. E. Minor, and R. D. Marshall, "The Darwin Cyclone: Valuable Lesson in Structural Design," *Civil Engineering*, Vol 45, No. 12 (1975).

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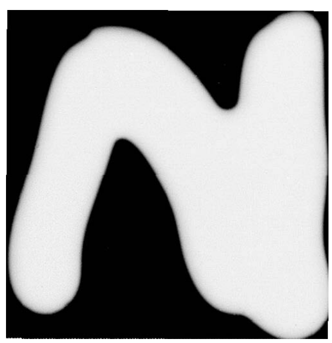
Material, design, and construction guidelines for vertical construction in desert and tropical regions / by Anthony M. Kao, Kevin Krumdieck.--Champaign, Ill. : Construction Engineering Research Laboratory ; Springfield, Va. : available from National Technical Information Service , 1978.
106p. : ill. ; 27 cm. (Technical report - Construction Engineering Research Laboratory ; M-239.

1. Building-tropical conditions. 2. Building-deserts. I. Krumdieck, Kevin. II. Title. III. Series: U.S. Construction Engineering Research Laboratory. Technical report ; M-239.



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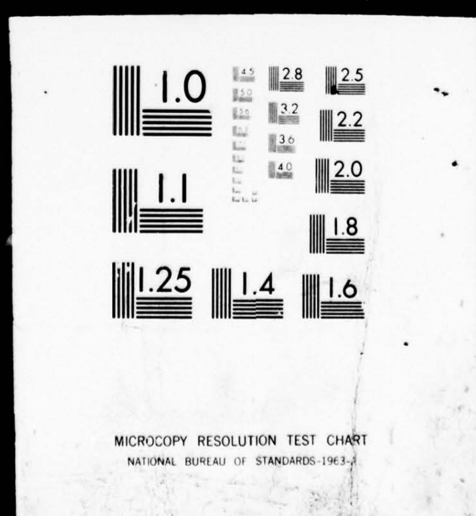

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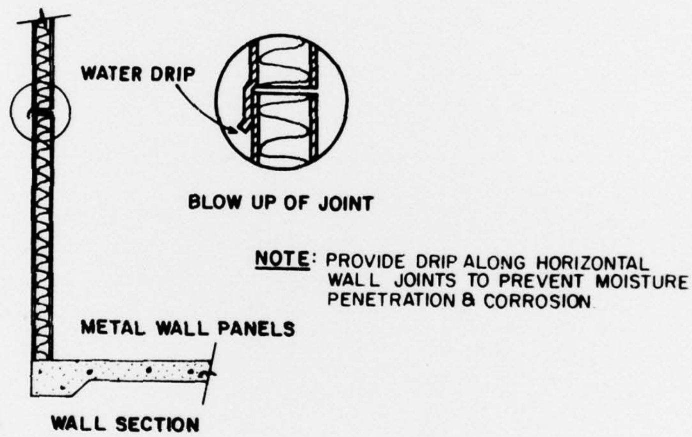
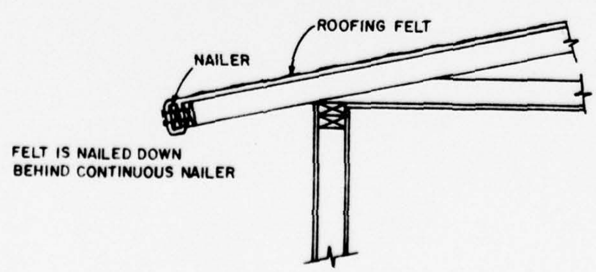
ERRATA SHEET for CERL Technical Report M-239, *Material, Design, and Construction Guidelines for Vertical Construction in Desert and Tropical Regions.*

These figures replace Figures 25 and 37b on pages 34 and 44, respectively, of Technical Report M-239, by A. M. Kao and K. Krumdieck, published in July 1978, by the U.S. Army Engineer Construction Engineering Research Laboratory.

Replaces Figure 25 on p 34 of CERL Technical Report M-239.



Replaces Figure 37b on p 44 of CERL Technical Report M-239.



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